Accepted manuscript, published version available at *Science*: https://www.science.org/doi/10.1126/science.adf1936

Body-based units of measure in cultural evolution

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Version note: This is the accepted version of a research article published in *Science* (Vol. 380, Issue 6648, pp. 948–954). Differences between this and the published version are only cosmetic. The published version is available at: https://www.science.org/doi/10.1126/science.adf1936

Abstract: Measurement systems are important drivers of cultural and technological evolution. However, the evolution of measurement is still insufficiently understood. Many early standardized measurement systems evolved from body-based units of measure, such as the cubit and fathom, but researchers have rarely studied how or why body-based measurement has been used. We document body-based units of measure in 186 cultures, illustrating how body-based measurement is an activity common to cultures around the world. We describe the cultural and technological domains these units are used in. We argue that body-based units have had, and may still have, advantages over standardized systems, such as in the design of ergonomic technologies. This helps explain the persistence of body-based measurement centuries after the first standardized measurement systems emerged.

One-Sentence Summary: Body-based units of measure have cognitive and behavioral advantages, which accounts for their use and long-term persistence worldwide.

Main Text:

The ability to measure things is central for human cultures. Throughout the history of human cultural evolution, systems of measurement have been products and drivers of cultural complexity (*1*–*4*). Global industry, technologies and commerce, as well as science itself, are largely built upon interchangeable units of measure. Standardization systems, such as the International System of Units, permeate the everyday lives of people across the globe. Some might say modern times are built upon our ability to measure the world. But how does the current system compare with those from the past, and what role has measurement played in the development of human societies?

Worldwide, many early standardized measurement systems are thought to have evolved from body-based units of measure (*3, 4*). For example, one of the earliest known standard measures, the royal cubit of Old Kingdom Egypt (ca. 2,700 BCE), evolved from the use of the natural cubit (the distance from one's elbow to the tip of the extended middle finger) (*5*). Harappan measurement systems were influenced by units such as the fingerbreadth (*6*), and various Ancient Mesopotamian measurement systems were abstracted from body-based units such as the foot, cubit, and pace (*4*). Traditional Chinese (*7*), Roman (*8*), Greek (*3*), Aztec (*9*) and Maya (*10*) measurement systems also used body-derived standards for measurement.

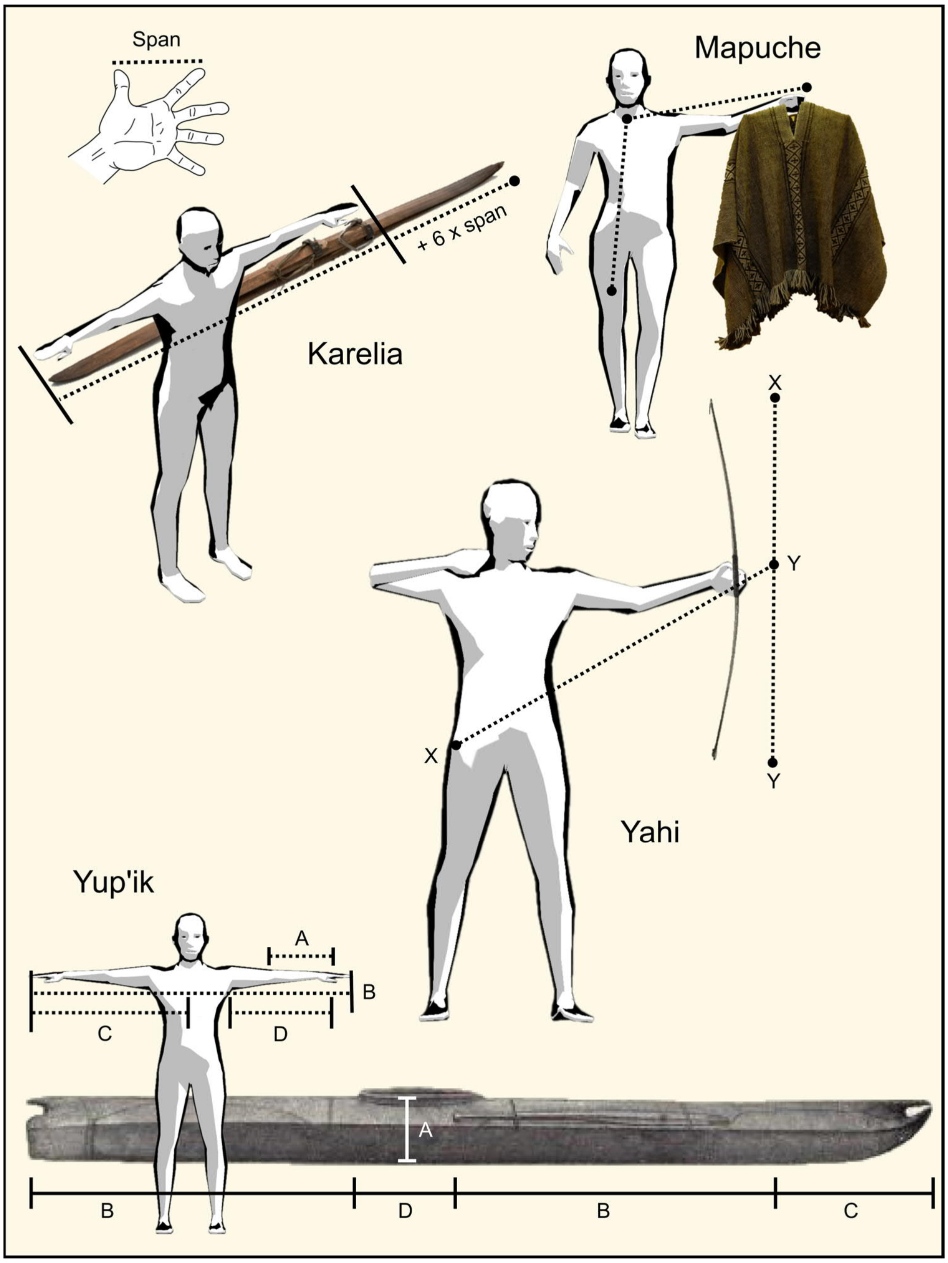
A unifying feature of past measurement systems is the use of individually variable body parts as units of measure (*1*, *3*, *4*, *11*). "Body-based units" are here defined as those units that are determined by using components of the human body. We analyze the use of body-based units of measure in 186 cultures across the world, describing common units and the cultural domains in which they are used. Body-derived yet standardized units of measure, such as the British Imperial foot, are not included in our data – even if the etymology of these units suggests an earlier use as body-based units.

Recent work has suggested that the cultural evolution of measurement can be characterized as a series of stages, starting from practical and gestural comparisons between objects, proceeding through unequal comparisons and initial standardization, followed by interrelated standardized units that form abstract and complex systems of measurement (*1*). Yet these are not historical stages that cultures transition through and leave behind, and units of various types may coexist (*1*). We find that a recurrent pattern in historical and ethnographic data on measurement is that body-based units have persisted alongside standardized measurement systems.

Not all cultures adopted standardized measurement systems to the same extent, and many cultures used body-based units well into the 20th and 21st centuries – hundreds to thousands of years after the first emergence of standardization. In the past, body-based measurement systems have often been described as primitive predecessors of standardized units (*12*). We question this notion and illustrate how body-based measurement systems have offered various problem-solving solutions and adaptive advantages in the evolution of human cultures and technologies (Fig. 1).

Drawing on our ethnographic dataset, we discuss potential cognitive-cultural causes for the long-term persistence of body-based measurement, documenting mechanisms by which body-based units have proven to be successful and competitive with standardized systems.

Fig. 1. Examples of objects designed with body-based units.
Top left: Karelian skis, early 1900s. The gliding ski was the user's fathom plus six spans (*36*). **Top right:** Mapuche ponchos were measured from the neck to halfway between the waistline and knee, and from neck to thumb with arm outstretched (*26*). **Center**: Yahi bow, early 1900s. The bow's length was from the opposite hip joint (X) to the tip of the outstretched arm (Y) (*37*). The width below and above the hand grip was four fingers for a powerful bow. (The posture pictured is not a typical Yahi shooting position.) **Bottom**: Yup'ik kayak from the Alaskan coast, late 1800s. The kayak's length was two fathoms (B) plus one half-fathom (C) plus the length of the cockpit, which was the length of an arm with a closed fist (D) (*19*). The kayak's height at the cockpit was one cubit with closed fist (A). The kayak's width was two cubits. **Images**: *Ski*: National Museum of Finland (CC-BY 4.0). *Poncho*: Wikimedia commons (CC BY-SA 2.0), by Pontificia Universidad Católica de Chile. *Bow*: Internet Archive (identifier: yahiarcherysaxton00poperich). *Kayak*: Internet Archive (identifier: eskimoberingstrait00nelsrich). *Human models*: MakeHuman. *Hand*: Wikimedia commons (FAL 1.3), by JNL.



Results

We document body-based units in 186 cultures (Fig. 2A). Table 1 lists the most common units. Variations of the fathom, hand span and cubit are most frequent and exhibit striking similarities between cultures around the world (Fig. 2B–D). We also find 62 cases of activity-based units of measure. These are units based on bodily activity, such as "a day's travel by foot" (measure of distance), or "a day's plowing" (measure of area).

Cultures in our dataset are coded based on their inclusion in the Standard Cross-Cultural Sample (SCCS) to mitigate Galton's problem (see Materials and Methods for further discussion). In total, our dataset includes evidence of body-based measurement in 99 SCCS cultures (ca. 53% of all SCCS cultures). The SCCS subset allows us to better estimate the independent use of specific body-based units (Table 1). In the SCCS subset, the fathom (44 observations; 23.7% of all SCCS cultures), hand span (41 and 22%, respectively), and the cubit (40 and 21.5%) are the most frequent body-based units, suggesting that these units appear most commonly in human cultures (note that their frequency might also be a product of remarkably distant common origins). These estimates are only lower bounds, because body-based measurement has often gone undocumented.

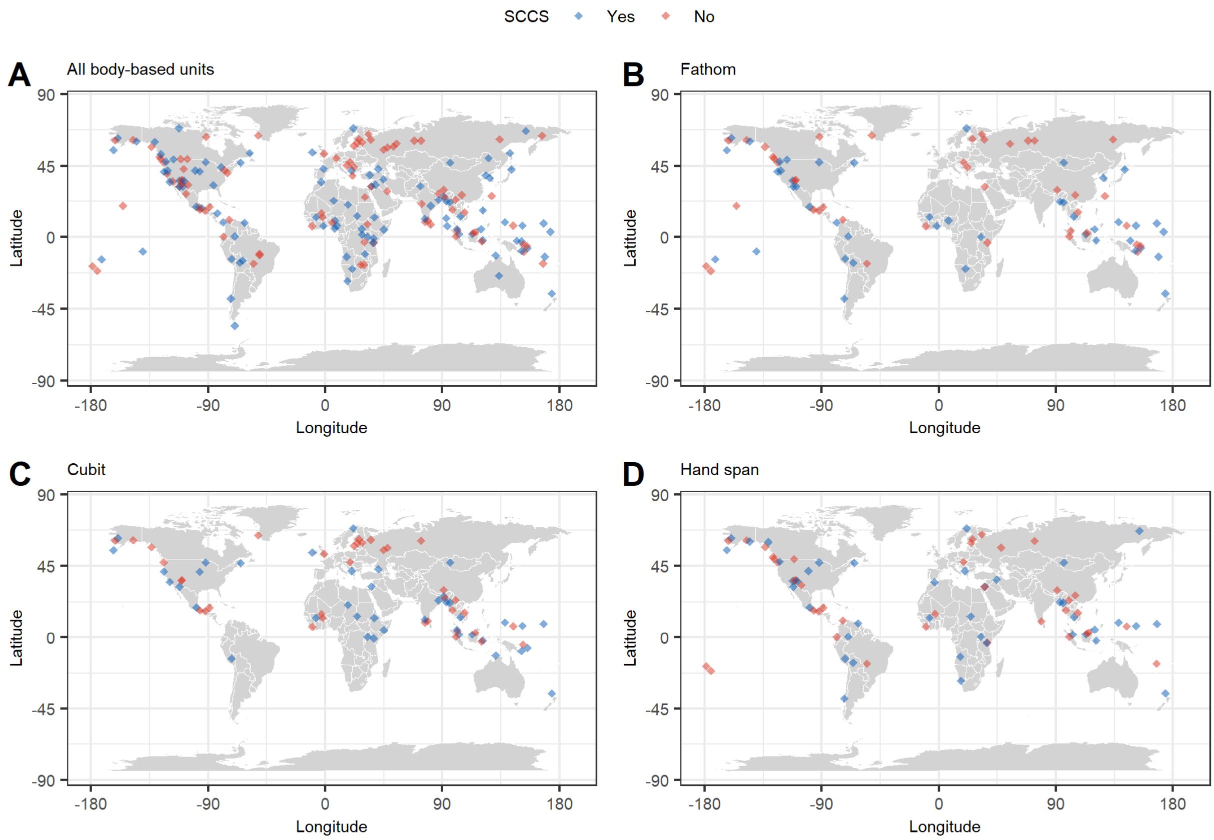
In Table 2, we present a typology that describes the behavioral and cultural domains in which body-based units are used. We find body-based units especially common in the design of technologies, highlighting the important role of body-based units in technological evolution. We also document noteworthy use of body-based measurement in trade, agriculture, and rituals. Body-based units are mostly one-dimensional measures of length. However, cases of measuring area, volume (e.g., handfuls) and temperature are also documented.

Body-based units are found on all inhabited continents (Fig. 2A). Our results suggest that cultures around the world use very similar units (Fig. 2B–D). Mostly, body-based units are used in specific contexts, such as the measurement of a particular technology. However, our dataset also documents elaborate domain-general systems of body-based measurement, such as those among the Māori, Mara, Siwai, Trobriand, Iban, Katu, Kwakwaka'wakw and Chuuk.

Fig. 3 depicts the temporal distribution of the evidence of body-based measurement per each cultural region in our dataset. We find ample evidence for the use of body-based units in the 20th century. According to global reviews on historical metrology (*3*, *4*), most cultural regions had encountered standardized units of measure prior to the 20th century. Table S1 and Fig. 3 document, for each cultural subregion in our dataset, plausible early dates for the introduction of standardized measurement systems. Our dataset supports the general claim that body-based measurement systems have persisted despite potential access to standardization (Fig. 3).

Definitive claims on culture-specific retention of body-based units are difficult to make because the first emergence of standards often pre-dates the categorization of contemporary cultures, and culture-level evidence on encounters with standardized measurement systems is sometimes lacking. However, we surmise that within cultural regions, such contact would often occur and therefore knowledge of standardization would spread, and in many cases cultures could opt to adopt nearby standard units if they deemed them necessary or superior.

Fig. 2. Cultures in the dataset on a world map. The maps illustrate the widespread practice of body-based measurement. Each diamond represents a culture in the dataset. Cultures included in the Standard Cross-Cultural Sample (SCCS) are colored blue, other cultures are colored red. Map A depicts the distribution of all documented cultures with body-based units of measure. The other maps illustrate the three most common body-based units in the dataset: the fathom (B), cubit (C), hand span (D). Locations of cultures are based mostly on eHRAF coordinates. Note that locations are only rough estimates, since many cultures and ethnic groups are geographically widespread and/or mobile.



In certain cases, the retention of body-based units is more obvious. For instance, in the Middle East, where some of the first known standardized measurement systems evolved three to five millennia ago (*3*, *4*), body-based units have been documented as late as the 21st century (Fig. 3). Similarly, in various European regions, the first emergence of standards dates to the Roman Republic or Hellenistic Greek eras or even prehistoric times (*13*), but body-based units are still documented from the Middle Ages to the 1900s (table S1; Fig. 3). In an exemplary case, the Zapotec have used body-based units in the mid-to-late 20th century, even though at the time Spanish standards were well-known, and standards such as the vara (the rod) were introduced centuries earlier (*14*). The Zapotec have even named some of their body-based units after Spanish standards (*14*). Our dataset documents similar cases of retention in Hawaiian, Turkish, Yup'ik, Palestinian and Mapuche cultures. Moreover, as discussed below, body-based measurement is still used in some contexts in the industrialized West.

Fig. 3. **Timeline of standardization and recorded body-based measurement.** For each cultural region in our dataset (based on the HRAF regional categories), we defined the earliest known case of standardized units of measure (blue points), the coverage dates of ethnographic evidence for body-based measurement (red segments; darker segments signify overlap of evidence), and the most recent evidence for body-based measurement (red points). These dates are defined and described in more detail in table S1.

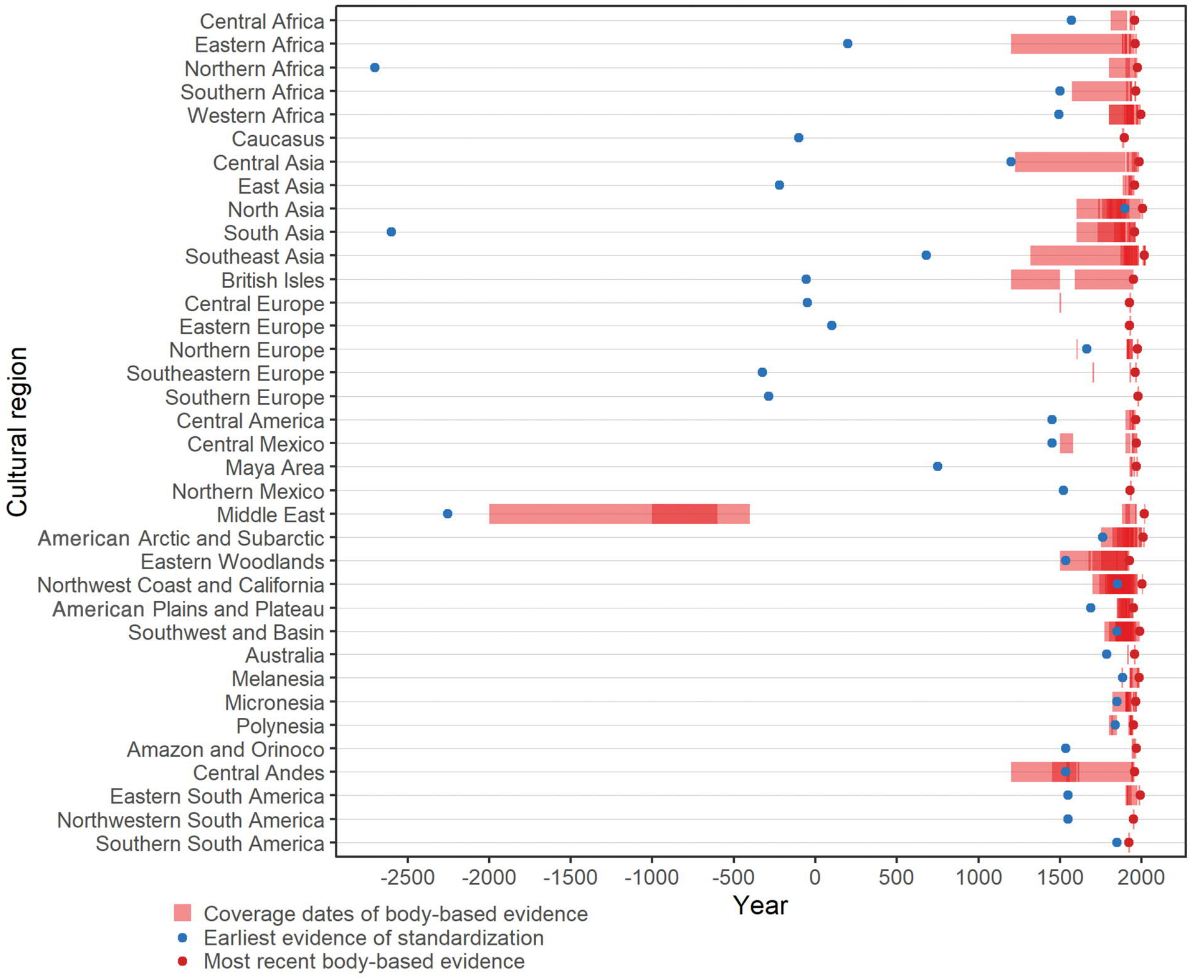


Table 1: **Body parts used for measurement.** The fifth column counts the fourth column as a proportion of the total 186 SCCS cultures, describing the proportion of all SCCS cultures in which we have documented each body-based unit of measure with. Incidence refers to the number of cultures with the specific unit. Note that the parity in the number of cultures (186) in our dataset and in the SCCS is coincidental.

Unit	**Description and variations**	**Incidence (full dataset)** (N = 186)	**Incidence (SCCS subset)** (N = 99)	**% of total SCCS** (N = 186)
Fathom (arm span)	Distance between fingertips of outstretched arms. Variations include, e.g., the fathom with closed fists.	85	44	23.7%
Hand span	Distance between the tip of the extended thumb to the tip of one of any four other fingers on an outstretched hand.	81	41	22.0%
Cubit (ell)	The distance from the tip of the elbow to the tip of an extended finger (typically the middle finger). Also sometimes measured to the closed fist or wrist, or from elbow crease to fingertips, etc. Other similar forearm-based units are included.	76	40	21.5%
Arm length	Any units based on the length of an arm, typically from tip of outstretched fingers to one of the following: armpit, shoulder, or middle of chest (half-fathom).	66	35	18.8%
Activity-based measures	Units of measure based on physical activity, such as a “day’s journey” or “stone’s throw” (linear measures) or a “day’s worth of plowing” (measure of area).	63	32	17.2%
Finger width	Width of one or multiple fingers (or fingernails), excluding the thumb (cf. “thumb width”).	44	21	11.3%
Hand width	Width of the palm (also known simply as the “palm”). Also includes the width of four fingers or the fist, or the circumference of the palm.	39	16	8.6%
Pace	A pace, step or stride.	34	19	10.2%
Finger length	Length of any of the four fingers, thumb excluded (cf. “thumb length”). Includes the length of finger joints and combinations thereof.	34	18	9.7%
Height	A person’s height from the sole of the foot to the tip of the head, or to the tip of vertically extended arms. Also includes measures of height to other specified points of the upper body (e.g., navel, eyes, forehead).	28	16	8.6%
Foot	Inner or outer length of the foot. Also includes foot width.	27	15	8.1%
Handful	Cupped hand (handful) or two cupped hands (double handful), a measure of volume.	26	18	9.7%

Thumb width	The width of the thumb (including nail-width).	15	8	4.3%
Fistmele	Width of the fist with an extended thumb (similar to “thumbs up” gesture).	14	5	2.7%
Thumb length	The length of the thumb or thumb joint(s).	14	7	3.8%
Hand length	The length of a hand, typically from the wrist joint/crease to the tip of the middle finger.	12	7	3.8%
Arm thickness	As thick as the arm (or wrist).	7	5	2.7%
Armful	As much as a person can carry in both arms (a measure of volume), or the circumference the arms can surround.	7	6	3.2%
Pinch	A small measure for volume measured by pinching the thumb against the tip of a finger (e.g., a “pinch of salt”).	7	6	3.2%
Leg length	The distance from the sole of the foot to the knee or hip.	5	2	1.1%
Ring	Measure of circumference made by pinching the tip of a finger to the thumb (similar to the “OK” or “ring” gesture).	5	4	2.2%
Leg thickness	As thick as (any part of) the leg.	3	2	1.1%

Table 2: **Behavioral and cultural domains in which body-based units of measure are used.** The third column describes the incidence of the trait in the full dataset (i.e., the number of cultures the trait appears in). The fourth column describes the number of SCCS cultures in the dataset that are recorded with each trait.

Theme	**Description**	**Incidence** (N = 186)	**Incidence (SCCS subset)** (N = 99)
Technological domains			
Garments and cloth	Body-based units are used in the design, measurement, or weaving of garments or cloth. Includes textiles, clothes, footwear, and other wearable items.	44	23
Building	Body-based units are used in design or construction of buildings or other infrastructure. Includes carpentry.	34	17
Weaponry	Body-based units are used in the design or construction of weapons (bows, spears, etc.).	31	17
Transport	Body-based units are used in the design or construction of transport-related technologies, e.g., kayaks, canoes, boats, skis, equestrian items, sleds, etc.	24	13
Household	Body-based units are used in the design or construction of other household items, such as mats, pottery, utensils, looms, etc.	21	12
Fishing tools	Body-based units are used in the context of fishing (also crabbing, shellfish harvesting, etc.), such as the measurement of fishing nets, lines, hooks, and harpoons.	13	9
Agricultural tools	Body-based units are used in the design or construction of agricultural technologies, such as scythes or plows.	5	1
Instrument	Body-based units are used in the design or construction of musical instruments.	3	0
Other cultural domains			
Trade	Body-based units are used for trade, in markets and barter, or for measuring units of currency.	35	21
Agriculture	Body-based units are used in agriculture (or horticulture), e.g., in measuring cultivated land or agricultural products, or distance between sowed seeds.	29	14
Ritual	Body-based units are used in ritual, ceremonial, religious, burial, or divination purposes.	23	12
Animals	Body-based units are used to measure the size (or value) of animals/livestock.	9	5
Cooking	Body-based units are used in cooking and the measurement of food items.	6	3
Medicine	Body-based units are used for medical purposes.	3	2
Games	Body-based units are used in the context of games or play.	2	2
Dimensionality			
Linear	Body-based units measure linear distance (one-dimensional; between two points).	169	90
Area	Body-based units measure area (two-dimensional space).	29	13
Volume	Body-based units measure volume (three-dimensional space).	27	17

Other			
Ergonomic	Instances where body-based units of measure are mentioned to be used in designing custom-sized (ergonomic) technologies.	25	12
Temperature	Instances where the body is used to measure temperature (e.g., when something is "too hot to touch" or of "body temperature").	2	1

Discussion

From the dataset we identify four cognitive-cultural mechanisms that help explain why body-based units have been used to begin with, and why they were still often preferred to standardized units up until the recent past.

1. Ergonomic design

Body-based units have the advantage that they afford custom-made ergonomic designs in ways that standardized systems often overlook (Fig. 1). We find references to ergonomic design by body-based units of measure in 25 cultures (Table 2). We take indigenous ergonomics to be an especially favorable domain for the use of body-based units. Erased by the industrial revolution, ergonomics largely re-emerged in the Western world only after WWII (*15*).

Illustrative evidence of ergonomic design is found in kayak-building. A responsive kayak requires proper positioning of the body. Consequently, no one-size-fits-all design serves all kayakers. Kayaking cultures, including the Yup'ik (*16*) and Greenlandic Inuit (*17*), have used body-based units to correct kayak designs for interpersonal variation. Kayaks were typically designed "by and for their user for the best possible performance" (*18*), to ensure "perfect fit between the kayak and its maker" (*16*). Yup'ik kayaks were designed with various body measures (*16*, *19*), as described in Fig. 1. Similar methods are used in the design of paddles: a common length for a double-bladed Greenland paddle is the user's fathom plus one cubit, and the blade-width is determined by the maximum breadth one can grip (*17*).

Body-based units have also guided the design of tools such as skis. For example, a Khanty ski maker might measure ski width with their outstretched "finger-and-thumb span plus two fingers", and ski length to their eyebrows (*20*). This affords ergonomic balance: too narrow skis would sink into soft snow, and too wide skis would be cumbersome and carry excessive snow. 16th century evidence suggests the length of Saami skis were the height of the user for the kicking ski, and the user's height plus foot for the gliding ski (*21*) (see also the Karelian skis in Fig. 1). In fact, in contemporary skiing cultures, it is still commonplace to use one's own height to determine ski and pole length. For repetitive and injury-prone practices such as farming, ergonomic tool design is especially important (*14*). Various Zapotec tools were measured with the user's own body measures, such as the Zapotec vara (fathom), to ensure that the farmer's tools (e.g., plows and axes) were custom-made and therefore ergonomic (*14*).

Weapons such as bows also require ergonomic design to ensure proper shooting form and draw length. Body-based bow design is found in various North American indigenous cultures. For instance, Ojibwe bow length varied with the stature of the bow's owner, measuring from "the point of the shoulder across the chest to the end of the middle finger of the opposite hand" (*22*) (see also

Yahi bow design in Fig. 1). Similar design is found in Europe, as documented in Edward IV's orders for every Englishman between 16–60 years of age to construct a longbow of their own height plus one fistmele (width of fist with thumb extended) (*23*). Even today, body-based units are being used in archery and bowhunting. A description of Yup'ik spear throwing highlights the importance of an ergonomically sized weapon (*16*):

> "They can use one *yagneq* (arm span) to measure when they make a *nanerpak* [seal spear]. People use their own body measurements. If a person uses a spear of someone taller than he is, it will be too long for him, and he will throw it differently. But when they make it to size, it can hit the target when thrown."

Custom tailored clothes and footwear are also made using body-based units. An illustrative example is the case of Mapuche poncho design, depicted in Fig. 1. Indeed, even tailors in commercial economies today use body measures to ensure the custom-fit of garments.

These findings suggest that body-based units and indigenous ergonomics have played an important and typically overlooked role in the design and evolution of technologies worldwide. Not unlike today, cultures in the past have struggled with ailments caused by repetitive and intensive activities (*24*), and reducing strain through functional design would have been essential.

2. Motor efficiency

Body-based units afford convenient motor routines. For example, measuring slack items such as fishing nets or rope with standard rulers is impractical, as they must be outstretched for each partial measurement, and can be inconveniently long. On the other hand, manual measurement could be conducted with relative ease, using simple motoric procedures. Consider, for example, Samoan methods of measuring three-ply braid (*25*):

> "[T]he worker measures the braid by holding one end with the left hand and running it through the right as he stretches the arms to full length. The full arm span is called a ngafa. The right hand holds the farthest point of the first span and draws it into the left hand which seizes the point. The second span is run through and so on until the number of spans or ngafa are counted."

Our dataset documents similar techniques of using fathoms to measure nets and ropes around the world. The influence of such practices is still observable today: a standardized fathom is used for measuring water depth in the British Imperial system. A likely explanation for these similarities across cultures is the procedural ease by which the fathom suits the measuring of slack items.

3. Availability

Body-based units have the advantage that their use does not require additional, and often cumbersome, measurement tools. This provides access to easy measurement even for highly mobile populations. Availability is useful even in contexts where standardized measures exist. For example, as one Mapuche informant describes (*26*):

> "But I do not always have a meter measure handy; I know that my wima [the length from Adam's apple to tip of fingers of an outstretched arm] is nearly a meter and I use it."

4. Integration with local knowledge

Unlike standardized units, the use of body-based units is often restricted to specific practical tasks. Accordingly, they often account for local information in ways that standardized units overlook. This is especially the case with activity-based units of measure.

For example, the Nicobarese have conveyed canoe trip distances as quantities of young coconut drinks consumed (*27*). Hydration is an especially important factor in the saltwaters of the Indian Ocean, and it would make practical sense to measure journey distances with required hydration units. In addition, standardized units of length such as nautical miles would not alone account for local variation in currents, weather, and wind conditions, which can all affect physical effort and travel time (and therefore, the amount of hydration required).

Vernacular units may in fact be sensitive to local conditions, conveying relevant information that standardized measures disregard. For instance, the Ifugao have used the number of rests required as a measure of distance, which is reasonable given that the local mountainous terrain is highly variable, rendering standard linear measures less useful (*28*). Similarly, in some cultures, land is measured in terms of physical activity, such as a day's worth of plowing, which also naturally adjusts for variabilities in terrain quality (*29*). Such measurement units allow adaptation to practical local context in deliberate ways. These findings align with research suggesting that context-specific counting systems can have cognitive and practical advantages (*30*).

Finally, standardized units of distance may simply not be very useful in everyday local lifeways. Local societies typically know their surroundings very well, and there would be little need to measure distances between these points. For example, distances on the Ifaluk Atoll are so short and universally known by locals that "there is little need to discuss them" (*31*).

From rules of thumb to standardization

Our data show that body-based units were still used worldwide in the 20th century – close to five millennia after the emergence of the first known standardized units. Our analyses suggest that considerable time lags existed between the regional emergence of standardized units and the use of body-based units (Fig. 3). This may be due to practical advantages, such as ergonomics and availability.

Another potential (not mutually exclusive) explanation for the persistent use of body-based units is cultural inertia. Cultural innovations are often slow to spread, and new formal innovations that require auxiliary technologies and standardization are often delayed in their cultural diffusion. This traction is well-documented in histories of measurement (*2*, *32*).

We suggest that pressures for standardization grow mainly in large-scale societies, and particularly intercultural states and commerce. We therefore raise the possibility that the transition from body-based units to standardized ones often spread as a case of "seeing like a state" (*33*) and not only for practical purposes: standardized measurement systems were cognitive-cultural inventions that enabled seamless statecraft. The early use of standardized units typically revolves around governance and administration (*32*), whereas body-based units are more often used by manual workers and artisans (*14*, *16*). Statecraft-related activities such as intercultural commerce, regulation and taxation would have demanded standardization and divisibility in ways that body-based units of measure could not deliver. This would also explain why standardized units primarily emerge through the influence of empires and large states (see table S1).

Ultimately, idiosyncratic rules of thumb could not coexist with the demands of mass production. This is evident in industrialist Taylorist principles, which were antagonistic towards "inefficient rule-of-thumb methods" (*34*). Even if body-based measurement could serve manual workers, they could not be adapted to the strict requirements of factory workflows. The move from body-based measurement systems to standardized and abstract systems therefore reflects a larger break in human cultural evolution, one that has seen production systems evolve from local and heterogenous to global and homogenous. As a consequence, traditional units of measure are endangered in the broader cultural extinction event (*35*) that has followed globalization, industrialization and colonization.

Materials and Methods

Data collection

We collected a dataset that includes descriptions of body-based units of measure in 186 cultures or ethnic groups. The dataset, analysis code (R), and readme are available at https://doi.org/10.17605/OSF.IO/FEGVR. The dataset includes direct quotes from ethnographic sources, which provide detail and context on how body-based units of measure are/were used in each culture. Also provided are references to original sources, thematic codes (elaborated below), and culture-level details.

Our main source for ethnographic data is the online ethnographic archive eHRAF World Cultures (https://ehrafworldcultures.yale.edu/). First, we used subject-based search (OCM: "804 Weights and Measurement") to search for cases of body-based measurement. (Note that this subset of our dataset, with OCM code 804, is similar to the one used in (*1*).) Next, to capture instances not tagged with this subject code, we used keyword-based search on eHRAF (using keywords "finger", "measure", "cubit", "fathom", "thumb", "rule", "foot", "feet", "arm", "span", "stride", "length", "width", "height", "body", "unit", "fist", "palm", and "leg"). Finally, we supplemented the eHRAF data with a literature review, especially targeting areas and cultures not included in eHRAF. This involved searching through other archives and search engines (focusing on digital collections such as archive.org, Google Books/Scholar, and doria.fi). 158 cultures include data from eHRAF (but not exclusively).

We restricted data collection to cases in which cultures or individuals were described using personal body parts or proportions (anthropometrics) as units of measure. We also chose to include units of measure that denote physical/bodily activity, such as measuring distance by "a day's travel by foot" or "stone's throw". Our dataset does not include fully standardized measurement units or systems. We did not include standardized units that derive from body-based units, such as the British Imperial foot, the Japanese foot (shaku) or the Chinese foot (chi). Standardized measurement systems like these have been documented in detail elsewhere (*3, 4*). One challenge in data collection was distinguishing body-based units from homonymous standardized measures. For example, distinguishing a body-based foot from a British Imperial foot may be difficult from textual data alone, although often this is clarified by context. Moreover, body-measures are often used alongside standardized ones, which can make distinguishing between the two difficult. In dubious cases, we have written a clarification under the "Notes" column in the dataset.

Data analysis

We used inductive qualitative content analysis to analyze the dataset. The analysis method consists of reading through textual data, identifying recurrent and common themes, coding the themes, and assigning sections of text with codes. A single culture was coded at maximum once with a specific code. This is because a culture may be mentioned using the unit "fathom", for instance, in a variety of references. Since our analysis is only concerned with whether a culture is documented expressing a specific trait (e.g., the unit fathom), multiple recordings of the same trait only result in one code (and therefore, as one unit of incidence in Tables 1–2). We use two kinds of codes:

1. We created a categorization for body-based units of measure (Table 1). We emphasize that simple categories cannot capture all relevant nuances, and the dataset's text data should be referred to for a full-detail description.
2. We created a typology to define the cultural and behavioral context in which body-based measurement is used (Table 2). We also coded other relevant themes, such as whether the unit of measure is one of length, area, or volume.

To mitigate Galton's problem, we coded each culture in our dataset based on whether they are included in the Standard Cross-Cultural Sample (SCCS). Galton's problem is a common problem in cross-cultural analysis, where statistical analysis may be compromised due to lack of statistical independence. In the case of our dataset, the problem can be explained through the following example: our entire dataset contains 76 instances of the body-based unit cubit. However, this number alone is an unreliable indicator of the rate of independent use of this unit, since the cubit may have been transmitted horizontally between cultures. For example, the Finnish kyynärä, Estonian künar, and Vepsian künabrus all appear in our dataset as unique instances of the cubit, although their similar names suggest common Baltic-Finnic origin. Therefore, it might not be appropriate to consider them truly "different" cubits. SCCS has been designed specifically to include relatively unrelated cultures, therefore mitigating Galton's problem (*38*). Using the subset of our dataset that includes only SCCS cultures allows us to make more reliable inferences regarding the (relatively) independent use of specific body-based units. Of the 186 cultures in our dataset, 99 cultures are included in the SCCS. Note that the fact that both the SCCS and our dataset contain 186 cultures is a coincidence. Tables 2 and 3 include descriptive analyses of our entire dataset as well as the SCCS subset of our dataset.

Next, we assessed evidence on the question of whether body-based units of measure persist after the emergence of standardized units of measure. We consulted encyclopedias of historical metrology (*3, 4*) and more specialized literature to find plausible dates for the earliest appearance of standardized units for each cultural subregion in our dataset (for consistency, subregions are defined based on the HRAF subregion typology). This analysis resulted in table S1. We also defined dates of the latest recorded use of body-based units of measure (Fig. 3). This date was obtained from the coverage dates of the ethnographical data for each culture (the dates in which body-based units are described being used – not the date of the publication of the reference). In most cases, this data was readily available on eHRAF as either the "coverage date" or "field date" of the source literature. In other cases, this data was inferred from the reference text. By comparing the subregional earliest dates of standardization and our dataset's coverage dates for body-based units of measure (Fig. 3), one may gain an overall picture of the commonality of body-based measurement practices after first regional emergence of standardization (but see Results section for caveats on making culture-level claims with this data).

We acknowledge that our dataset may be biased by research interests of scholars, who have disproportionately favored the study of some cultures and behavioral domains over others. Our data on body-based units dates mostly from the 20th and 19th centuries, although much earlier cases (and contemporary ones) are also reported (Fig. 3). For the sake of coherence, we choose to refer to all data in the past tense. This does not exclude the possibility that reported body-based units are still in use today. To facilitate future linguistic and cross-cultural analysis, we have coded the dataset based on whether the local names of body-based units are described, and we also defined Glottolog language identifiers for each culture. However, we do not conduct linguistic analysis in the present manuscript.

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Acknowledgments: The authors thank members of the Past Present Sustainability Research Unit for valuable feedback during the writing of this article. We also thank three anonymous reviewers for valuable constructive feedback.

Funding:

Academy of Finland grant 347305 (ROK)

Academy of Finland grant 338558 (JTE, ROK)

European Union's Horizon 2020 Research and Innovation Programme grant 869471 (JTE, MAM)

KONE Foundation grant "Arkistotiedon käyttö ympäristöntutkimuksessa – pohjoisen sosioekologinen ympäristöhistoria työkaluna ympäristömuutosten ymmärtämiseen" (JTE, MAM)

HELSUS postdoctoral grant (ROK)

Author contributions:

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Investigation: ROK, MAM, JTE

Visualization: ROK

Funding acquisition: ROK, MAM, JTE

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Writing – review & editing: ROK, MAM, JTE

Supplementary Materials

Table S1

Competing interests: Authors declare that they have no competing interests.

Data and materials availability: The body-based unit of measure dataset is available at https://doi.org/10.17605/OSF.IO/FEGVR. Also included is a readme file with instructions for the interpretation of the dataset, as well as the R code used to analyze the data and produce figure 2 and tables 1–2.

Supplementary Materials for

Body-based units of measure in cultural evolution

Table S1: **Plausible dates and sources of early standardized units of measure.** For each subregion in the HRAF typology of cultural regions, the table presents some plausible candidates for dates and sources of the earliest attested standardized units of measure. We refer the readers to more complete encyclopedias (*3*, *4*) for further information. The fourth column indicates, for each subregion, the years (CE, unless otherwise noted) or year-ranges in which body-based units have been reported in our dataset's reference base.

Region (HRAF)	Cultural subregion (HRAF)	Plausible date(s) and source(s) for early/earliest standards	Coverage dates of body-based evidence
Africa	Central Africa	The Kanem–Bornu Empire, under Mai Idris Alooma (ruled ca. 1571–1603), introduced standard units of measure (*39*). European colonial regimes (especially Belgium) introduced metric units in the late 19th century (*3*).	1812–1911 1925 1933–1946 1951–1958
Africa	Eastern Africa	Roman (and Byzantine) influence in Ethiopia is recorded from the 3rd–7th centuries CE, which may have introduced Roman standards (*4*). Later standardization may have been introduced through Arab and Islamic influence from the 8th century CE onwards (*4*). Yekuno Amlak of the Ethiopian Empire introduced standards in the 1270s (*3*).	1200–1900 1879–1885 1880 1893–1911 1895–1907 1900–1910 1900–1958 1924 1927–1929 1960
Africa	Northern Africa	In Old Kingdom Egypt, standardization (e.g., of the royal cubit) is recorded as early as ca. 2700–2500 BCE (*3*, *5*). Later, especially Roman influence from ca. 40 BCE would likely have introduced standardized Roman units to Northern Africa (*3*, *4*).	1800–1963 1900–1931 1959–1974
Africa	Southern Africa	Portuguese colonies (in contemporary Angola around the 16th century), Dutch colonies (around South Africa from the mid-17th century), and later British and German colonial influence especially in the 1800s introduced European standards (*3*, *4*). Influence from Arab traders in the 18th century is also likely (*4*).	1575–1902 1900–1907 1904–1944 1908 1929 1930–1934 1956–1957 1958–1966
Africa	Western Africa	The Mali Empire was established in the region ca. 1230, followed by the Songhay Empire. Askia the Great (ruler of the Songhay Empire ca. 1493–1528) introduced a uniform system for weights and measures (*3*). From the mid-19th century the region saw increased British and French colonial control, which would introduced the metric and British Imperial systems (*3*, *4*).	1800–1901 1800–1936 1890–1954 1900–1915 1908 1909–1953 1911 1921–1955 1931–1949 1935

			1950–1996 1967 1968–1969
Asia	Caucasus	The region was under Roman influence from the second century BCE, and later under both Byzantine and Persian (Sassanid) rule, which would have introduced Roman and Persian standards to the region. Earlier (e.g., Hellenic) standards may also have been introduced. (*4*)	1880–1894
Asia	Central Asia	From the 13th or 14th century, the Mongol Empire used standard units of measure influenced by Chinese and Persian units, and unified the system of weights and measures in the area under their rule (*3*, *40*).	1225–1900 1904–1925 1911–1920 1925–1985 1940–1959 1953–1972
Asia	East Asia	In China, standardization of units of measure can be dated at least to the Qin dynasty, when emperor Qin Shi Huang (r. 221–210 BCE) standardized units of measure (*41*). Later standards were introduced in the Han dynasty (from 202 BCE). Earlier standardization is also plausible. (*42*) Chinese units had considerable influence on nearby regions (*3*, *4*).	1883–1885 1896 1900–1930 1924–1956 1920–1936 1933
Asia	North Asia	The metric system was adopted in the Russian Federation by 1899, and in 1900, fundamental national units were defined (*3*). The Soviet Union adopted the metric/SI system in 1925 (*4*). Earlier Russian measurement standards existed, but evidence of their influence in North Asia is scarce.	1600–1900 1733 1760–1820 1785–1794 1800–1927 1850–1880 1895–1902 1998–2005
Asia	South Asia	Early standardization in the Indus Valley can be dated to the Harappan Period (2600 to 1900 BCE) (*6*).	1602–1902 1730–1900 1830–1875 1869–1880 1871–1901 1881–1951 1911–1933 1924–1928 1933–1939 1943–1954 1949–1955 1954–1956 1954–1956
Asia	Southeast Asia	Architectural analysis from 7th century Khmer cities such as Prasat Sambor suggests that they were built with some standard units of linear measure (*43*). The Pagan Empire is known to have standardized various units of measure as early as the early 11th century (*44*). Many Southeast Asian regions, such as parts of contemporary Vietnam, were also under Chinese rule from the 2nd century BCE, by the time which the Chinese had established	1320–1899 1870–1910 1890–1901 1892–1932 1900 1900 1900–1951 1900–1979 1910–1922 1924–1939 1937

		standardized units of measure (see entry under row East Asia).	1939–1943 1949–1973 1950–1951 1959–1966 1964–1965 1973–1978 1977–1981 2006 2013 2014 2018
Europe	British Isles	Evidence of consistent standard linear measures in monuments and artifacts exists from Neolithic Britain (third millennium BCE) (*13*). Notable proportions of the British Isles were under Roman rule from the 1st century BCE (and more completely from 1st century CE; except for Ireland, although Roman influence did reach Ireland too). By this time the Romans had standard units of measure. Around 1266–1303, in *Compositio Ulnarum et Perticarum*, English standards were established for linear and area measures. (*3*, *4*)	1200–1400 1400–1500 1590–1950
Europe	Central Europe	Various Central European regions were under significant Roman influence or occupation from ca. the 1st century BCE. By this time the Romans had standard units of measure.	1498 1927
Europe	Eastern Europe	Various sources of standards exist. Roman rule and influence in Eastern Europe is recorded especially from the 1st century CE. In the 13th century, Mongol units may have been introduced (see entry under Central Asia). In the Russian Empire, notable attempts at standardization are recorded from 1797 onwards (*45*).	1927
Europe	Scandinavia (Northern Europe)	In 1665, units of measure were standardized under Swedish law (*3*). Russian standards emerge especially in the late 18th century (see Eastern Europe). Earlier local standards have also existed, and access to other standards is also likely owing especially to Baltic medieval trade networks.	1600 1907–1922 1910 1911 1912 1913–1947 1920–1922 1927 1936 1971–1976
Europe	Southeastern Europe	The Greeks drew influence from Egyptian and Babylonian measurement systems. Standards varied by locality and were used especially in Mediterranean trade. Early standardized units of length are documented during the reign of Alexander the Great (ca. 325 BCE), but likely existed even earlier (*46*).	1700 1926–1933 1960
Europe	Southern Europe	The first known legal regulation of weights and measures in Rome is the *Lex Silia de ponderibus publicis* of ca. the mid-3rd century	1976–1979

		BCE (*8*). Roman units are known to have been influenced by earlier Hellenic units, which in turn were influenced by Egyptian and Babylonian units.	
Middle America and the Caribbean	Central America	Aztec standards (e.g., linear units based on land rods) have been documented from the turn of the 15th and 16th century (*47*). Following the Spanish conquest (from ca. 1519), the Aztec system (which also included various body-based units) was correlated with the Castilian (standardized) system. (*3*)	1900–1965 1927 1940–1941 1943–1948
Middle America and the Caribbean	Central Mexico	See Central America.	1500–1579 1900–1933 1940–1958 1940–1967 1957–1959 1965–1967
Middle America and the Caribbean	Maya area	Studies on Late Classic Mayan architecture suggest that units of measure seem to have been standardized, at least to a notable extent, from around 750–1000 CE. These units were likely derived from body-based measures (such as the arm span). Standards varied between communities. (*10*)	1927–1933 1932–1936 1938–1944 1950–1960 1967–1968
Middle America and the Caribbean	Northern Mexico	Spanish colonialists would likely have introduced standardized units of measure to the regional vicinity from the 16th century. A decree from 1801 stipulated the use of standard linear and weight measures in the region of Mexico. (*3*)	1930–1931
Middle East	Middle East	The Mesopotamian region has some of the earliest cases of standardization. Perhaps most notably, under the reign of Naram-Sin of the Akkadian Empire (ca. 2254–2218 BCE), many competing measurement systems were unified by single official standards (*3*). In Old Kingdom Egypt, standardization is recorded as early as ca. 2700 BCE (see Northern Africa).	1000 BCE – 600 BCE 2000 BCE – 400 BCE 1880–1947 1900–1928 1947–1955 1957 1960 2015
North America	Arctic and Subarctic	By the latest, standardization was introduced by the United States (e.g., through the acquisition of Alaska in 1867), Denmark (through its claim on Greenland in 1921), Britain (through its control of New France by 1763), or Canada (by control of the North-West territories in the 1870s) (*3*, *4*).	1750–1975 1820–1924 1850–1929 1883–1935 1905–1925 1907 1909–1910 1930–1940 1932–1940 1933 1934–1956 1940–1945 1942–1953 1958–1970 1960–2004 1985–2003 2010

North America	Eastern Woodlands	Various Spanish, British, and French colonies introduced European standards from the 16th to 18th centuries onwards (*3*).	1500–1910 1675–1690 1700–1912 1750–1912 1844–1850 1900–1925 1908–1911
North America	Northwest Coast and California	British Columbia became part of the Dominion of Canada in 1871. By then, Canada used both British and metric systems (along with other regional standards) (*3*). Spanish (standardized) units of measure are documented in the region of contemporary California pre-1860 (*4*). From 1853, the Territory of Washington was incorporated to the United States. By then, the United States used both British Imperial and metric systems (*3*). Earlier introduction of standards is possible, especially since the region saw Spanish, Russian and British trade from the late 1700s.	1700–1910 1741–1972 1775–1980 1790–1956 1800–1925 1820–1949 1840–1924 1850–1933 1850–1937 1881–1929 1885–1895 1900–1920 1903–1906 1912–1916 1920–1925 1924–1925 1925–1930 2001
North America	Plains and Plateau	European traders introduced standards from the late 17th century onwards, such as in the case of the Hudson Bay Company (*48*). Later mid-19th century standards were established under British, U.S. or Canadian governance (*3*).	1850–1940 1850–1951 1860–1926 1875–1911 1902–1911 1920–1925 1939–1940
North America	Southwest and Basin	Increasing U.S. influence and governance in the region from the mid-1850s would have, by the latest, introduced standards (especially British Imperial units) (*3*). Anasazi units do not seem to have been strictly standardized (*49*).	1774–1865 1800–1950 1840–1921 1840–1937 1846–1969 1849–1935 1879–1900 1881–1894 1890–1940 1901–1988 1928 1929–1931 1931–1935 1937–1942 1946
Oceania	Australia	British colonization from the late 1700s and especially 1800s introduced British Imperial standards (*4*).	1913 1954–1957
Oceania	Melanesia	European, especially German and British, colonial influence introduced British Imperial standards and the metric system from the late 19th century onwards (*3*). Earlier contact with standards through trade is plausible.	1877 1925–1927 1928–1929 1929–1930 1929–1930

			1938–1939 1938–1976 1973–1982 1975 1980–1984
Oceania	Micronesia	Spanish, German and British colonial influence introduced British Imperial standards and the metric system from the mid-19th century onwards (*3*). Earlier trade with Europeans is also recorded.	1820–1920 1900 1900 1900 1900–1938 1903 1907–1910 1908–1910 1909–1910 1910–1945 1912–1920 1916–1932 1947–1948 1947–1969 1961–1962 1963–1965
Oceania	Polynesia	British, U.S., French and German colonial influence introduced standards from the mid-19th century. Hawaii adopted the weights and measures of Massachusetts in 1840. (*3*)	1800–1950 1815 1920–1921 1927–1928 1928–1929 1928–1929 1928–1952 1930 1933–1934 1938–1939
South America	Amazon and Orinoco	See Central Andes.	1940–1941 1947–1958 1954–1969
South America	Central Andes	There is uncertainty about the precise use of standards in the Inka Empire, and units may have largely been anthropometric (*50*). The Spanish conquered the region ca. 1535, and by then, the Spanish would have used various standards for weights and measures. (*3*)	1200–1600 1200–1600 1450–1940 1539–1560 1610 1937–1938 1940–1941 1940–1942 1946–1952
South America	Eastern South America	Especially Portuguese influence and governance in Brazil is recorded from the mid-16th century onwards, introducing the Old Portuguese system of measures. Brazil adopted the metric system in 1862. (*3*)	1900–1974 1908 1908–1940 1983
South America	Northwestern South America	The region was annexed as a part of the Spanish colonies (Kingdom of the New Granada) in 1549. By this time the Spanish would have used a variety of standardized systems of measurement. (*3*)	1946–1950
South America	Southern South America	The metric system has been official in Chile since 1848, and prior to this Spanish	1918–1924

		measurement systems were used (*3*). Earlier contact with Europeans is also documented from the 16th century onwards.	