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Locke on measurement☆

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ABSTRACT

Like many virtuosi in his day, the English philosopher John Locke maintained an active interest in metrology. Yet for Locke, this was no mere hobby: questions concerning measurement were also implicated in his ongoing philosophical project to develop an account of human understanding. This paper follows Locke's treatment of four problems of measurement from the early Drafts A and B of the *Essay concerning Human Understanding* to the publication of this famous book and its aftermath. It traces Locke's attempt to develop a natural or universal standard for the measure of length, his attempts to grapple with the measurement of duration, as well as the problems of determining comparative measures for secondary qualities, and the problem of discriminating small differences in the conventional measures of his day. It is argued that the salient context for Locke's treatment of these problems is the new experimental philosophy and its method of experimental natural history.

> 'Tis of great use to the Sailor to know the length of his Line, though he cannot with it fathom all the depths of the Ocean. 'Tis well he knows, that it is long enough to reach the bottom, at such Places, as are necessary to direct his Voyage ... Our Business here is not to know all things, but those which concern our Conduct. If we can find out those Measures, whereby a rational Creature put in that State, which Man is in, in this World, may, and ought to govern his Opinions, and Actions depending thereon, we need not be troubled, that some other things escape our Knowledge.[1]
>
> (*An Essay concerning Human Understanding* (hereafter *Essay*) I. i. 6 [underlining added])

It is hardly surprising that the philosopher John Locke (1632–1704) had a penchant for metrical metaphors, for from the mid-1660s measurement was part and parcel of his everyday adult life. There are many facets to Locke's interest in metrology: he had an abiding interest in classical and biblical weights and measures[2]; he was fascinated by comparative weights and measures from different countries and regions; he helped devise a system of weights and measures for the Carolina colonies in connection with his work for the Lords Proprietors; and he argued in print about currency valuation. Locke's two original contributions to the *Philosophical Transactions* of the Royal Society both contain measurements and for most of his adult life he used instruments to take daily measurements of meteorological conditions.[3] Furthermore, while Locke was not a central player in the development of the science of metrology in his day, he did rub shoulders with most of the major figures and was fully apprised of developments in the field. In fact, Locke came up with three separate proposals for the standardization of measures that he hoped would be adopted by

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[1] See also Locke (1975) (hereafter *Essay*) I. i. 2, 3, II. xxviii. 20 and Locke (2006, p. 269).

[2] See Locke's annotated copy of Cumberland (1686), Bodleian Library (hereafter Bodl.) shelfmark Locke 8.177a, Harrison and Laslett (1971, #900). For lists of biblical money, weights and measures in Locke's journal from November 1677, see Bodl. MS Locke f. 2, pp. 338–45.

[3] See Locke (1697) and (1705). Locke's weather charts are in Bodl. MS Locke d. 9.

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the republic of letters, or, even better, by the government of his day. He devised a decimal standard for length, he put forward a recommendation against the devaluation of English silver coin and a proposal for calendar reform.[4] As things transpired, only the second of these proposals was adopted, and in this Locke seems only to have had a minor role.[5]

More importantly, however, Locke was one of the first English philosophers to implicate measurement in a broader philosophical project.[6] This paper argues that problems of measurement held an enduring and important place in the writing of Locke's famous *An Essay concerning Human Understanding*. It argues, further, that Locke's ongoing interest in metrology and his attempt to develop a standard of measure for length, are best understood as continuous with his broader philosophical project in the *Essay* which, in turn, is set within the broader context of the emergence of experimental philosophy and its program of natural history in the last four decades of the seventeenth century. Thus, if we are to get the measure of Locke as a philosopher we have to deal with the place of measurement in his thought: not simply his profound interest in metrology, but the central place of measurement in an experimental philosopher's conception of how we acquire knowledge of the natural world.[7]

At the outset of his quest to develop a theory of how the understanding acquires knowledge of the natural world, questions concerning the nature of measurement and a realisation of the need for standards of measure were in play. From then on, Locke's thoughts on these matters developed in tandem with a series of exciting developments in the science of metrology in his day, developments to which he was not merely an eye-witness but also a minor participant. In fact, Locke's journal, correspondence, notebooks, books and papers give us an almost unprecedented insight into how his involvement with developments in metrology intersected with the evolution of his famous *Essay*.

The sections that follow are in rough chronological order. Section One sets out the broader methodological context in which Locke undertook his long-term project to develop an account of human understanding. Section Two discusses Locke's proposed system of weights and measures for the Carolina colonies and examines his treatment of four problems of measurement as they appear in Drafts A and B of the *Essay* which date from c. 1671. Section Three traces the seam of evidence of Locke's interest in metrology and the development of his standard for length during his travels in France in the latter half of the 1670s. Section Four examines Locke's familiarity with the problem of longitude in the late 1670s. Section Five treats of measurement in the first edition of Locke's *Essay* and Section Six deals with developments in the 1690s after the publication of the *Essay*.

1. Measurement, experimental philosophy and natural history

By the mid-seventeenth century experiment had come to play a central role in the practice of natural philosophy. So important was it that a new natural philosophical methodology emerged in England in the 1660s that came to be called experimental philosophy.[8] It goes without saying that the primacy of observation and experiment in natural philosophy brought the problem of the standardization of measures to the fore. Quantities such as weight, length, time, and temperature were in desperate need of universal standards of measure. Furthermore, recent developments in natural philosophy had given rise to the need for measures of *newly discovered* qualities such as the spring or pressure of the air, the need for the *determination of constants*, such as the speed of sound and light, and the need for *accurate determinations* of location and elevation. In short, in the second half of the seventeenth century metrology obtained an importance that it had never before experienced. Of course, metrology had always been an essential feature of astronomy, but even that science was caught up in the new push for exactitude in the multiplication of observational data.[9]

It was not long before there was an institutional response to these issues. The standardization of length was the most pressing problem. It was addressed by the Royal Society of London as early as 1662. William Petty reported on his observations concerning Christopher Wren's suggestion that the pendulum be taken as a standard of length at the end of January 1662[10] and at the next meeting Wren was asked to find an alternative to the pendulum as a unit of measure. Various issues relating to the proposal were discussed, such as decimalization of the sub-units of length, relation to current local and international standards of length, etc.[11] An important treatment of the issues later appeared in John Wilkins' *An Essay Towards a Real Character and a Philosophical Language* of 1668, which reiterated that the determination of a natural standard or universal measure 'hath been esteemed by Learned men as one of the *desiderata* in Philosophy'.[12]

Yet there is a more specific context in which the place of measurement in natural philosophy in late seventeenth-century England needs to be understood and this is experimental natural history. Francis Bacon's vision for an architectonic – as distinct from classificatory – form of natural history that would include observations and experiments of phenomena from the heavens to the depths of the oceans, gave a central role to quantification: 'I demand that every thing to do with natural phenomena, be they bodies or virtues, should (as far as possible) be set down, counted, weighed, measured and defined'.[13] This new form of natural history was enthusiastically embraced and developed in the nascent Royal Society in the 1660s and its leading exponent was Locke's close friend and mentor Robert Boyle.[14] Boyle's own elaborate 'Designe' for natural history called for instructions on 'how to procure, æstimate, prepare and in some cases better *Mathematicall Instruments*, as Quadrants, Telescopes, Microscopes, &c. *Mathematical Tooles*, as Ballances, Statera's, Standards for measure &c.'.[15]

One such Baconian project was Boyle's history of the air which commenced with his ground-breaking *Spring of the Air* in 1660.[16] It is well known that in the spring of 1666 he supplied Locke with a barometer in order for him to measure the air pressure in the Mendip mines. The mission proved abortive, but within weeks Locke began his own contribution to the project by keeping

4 On Locke's recommendations against the raising of the value of money, see *Further considerations concerning raising the value of money*, Locke (1991, Vol. 2, pp. 410–81). For Locke's proposal on calendar reform, see Milton (2006).

5 For background and analysis of Locke's contribution to the English monetary crisis of 1695, see Patrick Kelly, Introduction, Locke (1991, Vol. 1, pp. 1–109).

6 A number of English philosophers and mathematicians before Locke discussed measurement. For the case of Francis Bacon, see Rees (1985), Pastorino (2011), Jalobeanu forthcoming and below. For Isaac Barrow, see Barrow 1684, lectures VI and VII.

7 Sadly, space does not permit a discussion of the cognate issue of Locke's view of the ontological status of space and time.

8 See Anstey and Vanzo (2012).

9 See van Helden (1989) for further discussion.

10 All dates are New Style unless otherwise indicated by '(OS)'.

11 See Birch (1756–1757, Vol. 1, pp. 74–5).

12 Wilkins (1668, p. 191).

13 Francis Bacon, *Parasceve* in Bacon (2004, p. 465); see also *Novum organum* I, 98, Bacon (2004, p. 157). For Bacon's conception of natural history, see Jalobeanu (2015) and Anstey (2011, chap. 3).

14 See Anstey and Hunter (2008).

15 Boyle (2008, p. 1).

16 Boyle (1999–2000, Vol. 1, pp. 141–301).

detailed measurements of meteorological conditions. His weather charts from this period of his life span from June 1666 to June 1683 (excluding the period of his sojourn in France) and were included in Boyle's *General History of the Air*, which Locke saw through the press after Boyle's death in 1692.[17]

2. Carolina and Drafts A and B of the *Essay*

Thus, by mid-1669 when Locke was appointed as secretary to the Lords Proprietors of the Carolina colonies, measurement was a familiar part of his day-to-day life. It is of singular interest, therefore, that in his capacity as secretary to the Lords Proprietors, Locke appears to have been involved in devising a set of weights, measures and a currency for Carolina. A manuscript draft endorsed 'Carolina Measures and weights' exists among the Shaftesbury Papers in the National Archives.[18] It includes lists of new measures of length, area and volume, as well as, weights and monetary denominations. The measures of length, area and solids are all in English inches and are set out in two columns with the English measures on the left and the proposed Carolina measures on the right. All of the names of the new measures appear to be original except for 'Acre Carolin' and the 'Quart Carolin'.

Three interesting features of the list of lengths imply that Locke had a hand in devising these measures.[19] First, the smallest unit of measure of length is called the gry and this, notoriously, was the name that Locke would later use for the smallest unit in his own recommendation for the standard of length. Second, like Locke's later standard, the Carolina measures for length are decimal and the gry was a thousandth part of a drom. The third feature that weighs in favour of Locke's involvement is the fact that the drom is 39.2 inches in length, in contrast to the English yard of 36 inches. Now, we know from a notebook entry made in 1679 that Locke had learned from the Royal Society's operator, Richard Shortgrave,[20] that 39.2 inches was his measurement of the length of the seconds pendulum (Wilkins had reckoned it at 39.25 inches[21]). It is highly likely that Locke acquired this information in connection with the Carolina measures, for, during this period Locke, who had been elected Fellow of the Royal Society in November 1668, was very closely associated with the Society. For example, on 11 February 1669 he was appointed, along with Boyle, Wilkins and others, to one of two Royal Society committees 'for considering and directing of experiments'. And he was elected to the Society's Council, along with Christopher Wren, on 30 November 1669.[22] Moreover, the very next month Locke began to make his daily temperature records 'by a Thermometer of the Royal Society's Standard', that is, by a Shortgrave thermometer.[23] All these facts go a long way to explaining both his reported interaction with Shortgrave and his involvement in the choice of the pendulum standard. Thus, as early as 1669 Locke was involved in the development of a standard measure of length based upon the seconds pendulum.

Not long after Locke commenced his work with the Lords Proprietors, he composed Drafts A and B of his famous *An Essay concerning Human Understanding*. This was a project of an entirely different nature, informed as it was by experimental natural philosophy with its method of natural history,[24] and yet the question of measures appears in both Drafts. In fact, in the extended discussion of the measurement of duration in Draft B Locke mentions Americans twice, an indication of both the temporal and conceptual connections between the two projects.[25]

Turning to the Drafts themselves, the first, Draft A, is not particularly concerned with the topic of measurement, however, Locke does mention, in passing, two measurement problems. First, some qualities, such as colour and heat, do not have measures whereby we can accurately compare one degree with another (A§11, Locke, 1990, p. 22). Second, our senses are not accurate enough to perceive very small differences in standard measures, such as an inch or foot (A§12, Locke, 1990, p. 24). He also asserts that there are two types of measurement: measuring by number and measuring by extension, and that the former is always certain whereas the latter is subject to error (A§§11–12, Locke, 1990, pp. 22–6).

Draft B, by contrast, contains far more material on measurement, material that is grouped together in two extended passages. In the first, Draft B §§41–48, Locke recycles and augments the Draft A passages. The context of this discussion is a series of points that Locke makes concerning the knowledge that can be acquired from our simple ideas. According to Locke, in addition to the knowledge of qualities of external bodies, we can have some knowledge of the relations between these qualities by comparing the simple ideas that these qualities produce in us. As he pointed out in Draft A, however, because we lack the means to measure the difference between, say, two ideas of heat, our knowledge of these relations is not exact. Sounds, for example, 'have no knowne certein natural measure to examine them as extensions have', though the difference in pitch might amount to something measurable such as 'either a different number of particles affecting the sense or a swifter motion (which is a kinde of extension)' (B§46, Locke, 1990, p. 152). Locke also develops his thoughts on the distinction between numerical and extensional measurement, which he now calls mathematical measuring and mechanical measuring respectively (B§42, Locke, 1990, pp. 149–50). Furthermore, in this passage Locke adds the new claim that our conventional measures of quantities such as length and volume are not 'determind in nature' (B§43, Locke, 1990, p. 150). Instead 'in mechanicall measureing there being noe other standards but voluntary v.g. an inch or a foot &c which therefor must be preservd in some materiall thing with which the standard is liable to vary' (B§42, Locke, 1990, pp. 149–50).

So, up to this point in Draft B Locke has raised three problems for mechanical measurement. First, we lack natural measures for comparative judgments about sensible qualities such as colour, heat and sound and are therefore restricted to rather imprecise comparisons between different determinate qualities. Second, there appear to be no natural measures of extension, so we are left to resort to conventions. And third, we are unable to detect minute differences in extensional measures, such as an inch or foot.

[17] See Boyle (1999–2000, Vol. 12, pp. 70–89). For further discussion, see Anstey (2011, chap. 3).
[18] The National Archives PRO 30/24/48, fols 71–2. David Armitage kindly alerted me to the contents of these folios.
[19] Roger Woolhouse claims that Locke devoted some thought to a system of coinage and measurement for Carolina, but provides no evidence. See Woolhouse (2007, p. 91).
[20] MS Locke c. 42, part 1, p. 88. Locke records in 1679 that he learned the measure from Shortgrave 'here to fore' and, given that Shortgrave died in 1676, it is most likely that Locke's communication with him was around 1669.
[21] Wilkins (1668, p. 192).
[22] See Birch (1756–1757, Vol. 2, pp. 346, 406).
[23] See Boyle (1999–2000, Vol. 12. p. 78); Birch (1756–1757, Vol. 4, p. 72); and Hooke (1665, pp. 38–9).
[24] Locke says at one point in Draft B that he has given the reader 'a true history of the rise & originall of humane knowledg', (B§31, Locke, 1990, p. 140). Later in the published *Essay* he would speak of his 'Historical, plain Method', *Essay* I. i. 2.
[25] See Locke (1990, Draft B §§101 and 122).

The second extended discussion of issues pertaining to measurement in Draft B concerns the measurement of duration (B§§101–126).[26] Locke claims in section 102:

> Time therefor to duration is as place to extension which is noe thing but examining or assigneing the distance of any two points by some common knowne measure as inches feet, yards miles, diameters of the earth &c. (B§102, Locke, 1990, p. 225)

Locke clearly thinks that we can treat duration as analogous to extension. Duration, however, is more problematic than extension for two reasons. First, and this is a strictly philosophical problem, it is difficult to give an account of the origins of the idea. And, second, it is more difficult to find adequate measures of duration than it is for extension.

As for the first problem, Locke claims that we acquire our idea of duration from 'reflection on the operation of our owne mindes in thinkeing. i e the appearance of severall Ideas in our owne mindes one after an other' (B§103, Locke, 1990, p. 225). We need not go into Locke's extended treatment of this problem, which involves an account of the acquisition of the idea of succession, as well as assumptions about 'certain bounds to the quicknesse & slownesse of the succession of these Ideas one to an other' (B§105, Locke, 1990, p. 228).[27] (Though it is worth noting that Locke appeals to the succession of ideas in our own minds as one of the means by which we establish a measure of duration.) Our concern is with the stage that follows on from the explanation of the origin of the idea of duration. In section 106, Locke tell us: 'Haveing thus got the Idea of duration, the next thing natural for the minde to doe is to get some measure of this common duration of things' (B§106, Locke, 1990, p. 231). In the case of extension we naturally 'get some measures to record or signifie certain parts or proportions of extension' using 'some knowne stated measure' and 'markeing out in portions of lasting matter as inches, feet, yards &c ... preserved as standards ... on solid bodies'. But when it comes to duration 'it falls out other wise & there in we can not bring our measures to that certainty we doe in extension' (B§107, Locke, 1990, p. 231).

This leads in to an extended discussion of establishing a metric for duration. Once again, we can pass over the details. The crux of the matter is that Locke acknowledges 'the periodicall motions of the sun or moone have been by the greatest part of man kinde made use of for the common measures of duration, & of late the motions of a pendulum' (B§108, Locke, 1990, p. 232), but that these periodical motions are not equal (each day is slightly longer or shorter than that which precedes and succeeds it). Moreover, because one pendulum swing succeeds another we can never compare them: we cannot be certain that any 'two successive diadroms of a pendulum are of the same duration' (B§109, Locke, 1990, p. 235).

More problematic still is the circularity involved in using the diadroms of a pendulum to measure the periods of the sun when the pendulum itself is calibrated using the periods of the sun (B§109, Locke, 1990, p. 235). This is now known as the problem of the circularity of coordination.[28] Nevertheless, Locke claims that we can have greater confidence in our measures for time 'if there be the concurrencee of other probable reasons to perswade us of that equality, & thinke those the most equall where most reasons doe concur to persuade us soe, as is in pendulums' (Locke, 1990, p. 235). Locke here in the very same section has both stated the problem of circularity of coordination and intimated that the solution to this problem is one of convergence of different measures through iteration.

Such was the situation for Locke when he completed Draft B in c. 1671. His philosophical reflections on the nature of the understanding had led him to touch on four measurement problems. (1) The apparent lack of natural or universal measures of duration and extension means that we have to resort to conventional measures for extension and time. (2) It is difficult to fix a standard measure for duration and, moreover, the measurements based on the diurnal motion of the Earth and the seconds pendulum face a problem of circularity. (3) We do not have standards of measure for comparative judgments about sensible qualities. (4) We are unable to discriminate fine differences in standard measures of length, such as the inch or foot.

The sections that follow in this paper reveal Locke's ongoing concern with these four problems and how they were eventually treated in the first edition of the *Essay*. The core problem, which also happens to be historically the most interesting, is the first, the lack of natural measures. As we shall see, for some years Locke clearly believed that this problem had been solved, only for his hopes finally to be dashed. As for the second problem, fixing a standard measure for duration, it is fair to say that some progress was made, though there is little evidence of this in the *Essay*. Locke did make some progress on the framing of the third problem, the sensible qualities, though in the end he despaired of ever finding a solution. He did, however, make a practical contribution to the fourth problem of discriminating fine differences from standard extensional measures, but this is to get ahead of our story.

3. Locke's travels in France

While Locke was brooding over the problems of measurement, Christiaan Huygens had set about sorting out the physics of pendulum motion and the design for the construction of a pendulum clock which, in turn, enabled greater accuracy in the determination of the length of a seconds pendulum.[29] His results were published in his *Horologium oscillatorium* (Huygens, 1673). Here is how he puts it:

> For the case in which each oscillation marks off one second, divide this distance into three parts. Each of these is the length of an hour foot .... By doing all this, the hour foot can be established not only in all nations, but also can be reestablished for ages to come. Also, all other measurements of a foot can be expressed once and for all by their proportion to the hour foot, and can thus be known with certainty for posterity. For example, ... the Parisian foot is related to the hour foot as 864 to 881. In other words, if the Parisian foot is given, then we would say that a simple pendulum, whose oscillations mark off seconds of an hour, has a length equal to three of these feet, plus eight and one-half lines. (Huygens, 1986, p. 168)

Huygens' proposal was to tie the problem of a metric for time to a metric for length. The key insight is that the seconds pendulum gives a natural, and therefore universal, standard for measure of duration which can be used for a standard for the measure of extension. As he

[26] There is a good deal of repetition in Draft B §§101–8 and the text as published should be regarded as containing overlapping variants of the same material. The positioning of this passage in the overall flow of Locke's argument is slightly odd. It follows immediately upon a long discussion of ideas of relation and so one would expect that a discussion of duration would continue as an additional example of a relational idea. However, section 101 is entitled 'Simple Ideas' and, rather than highlighting the relational nature of duration, the content of the early sections of the passage set the topic in contrast with the ideas of place and extension. In the published *Essay* Locke places a revised version of this material (*Essay* II. xiv) after the chapter on the simple modes of space and in the broader sweep of chapters on complex ideas. See *Essay* II. xii–xiv.

[27] For an ingenious attempt to fill out Locke's final view of the origins of our idea of duration, see Yaffe (2011).

[28] See van Fraassen (2008, chap. 5) and Tal (2013).

[29] See Harper (2011, pp. 198–9).

put it: 'all other measurements of a foot can be expressed once and for all by their proportion to the hour foot, and can thus be known with certainty for posterity'. Little wonder that he could claim 'the hour foot can be established not only in all nations, but can also be reestablished for ages to come'. In one fell swoop Huygens seems to have solved the first of Locke's measurement problems.

Locke had probably not seen Huygens' book when he left for France on 12 November 1675 where he remained for three and a half years. His first extended stay was at Montpellier. *En route* to Montpellier he stopped at Nimes where he took some measurements of its Roman amphitheatre. In the case of one very large stone he measured it with his 'sword', probably a flat wooden blade, which he says was 'near about a philosophical yard long'.[30] Given that he had distinguished the English yard from the drom in the Carolina measures, and that he would soon be speaking of a philosophical foot in relation to the seconds pendulum, it seems most likely that his sword was equivalent to a drom, and so was based on the seconds pendulum. This is all the more likely because from 3 to 26 January 1676 at Nimes and Montpellier he also recorded notes in his journal on Montpellier measures, the pan and the cane, as well as the Roman foot, using points in the margin to mark the length of a $^1/_4$ pan, $^1/_4$ Roman foot and $^1/_4$ French foot, and giving the equivalent measures for the Montpellier pan and cane in grys.

> Soe that a pan is ——— 752 grys
> A can of Montpellier ——— 6016 gr:
> The old Roman foot ——— 892 gr.[31]

All of this suggests that Locke had personally appropriated the Carolina standard for length and had had a measuring instrument made up accordingly.

While in Montpellier, he took other notes on the local and ancient weights, measures and coins, in some cases comparing them to the English measures.[32] In fact, notes on French provincial and classical weights and measures are scattered throughout the journal from the early months of the trip.[33] Then on 27 May 1676 he made a journal entry on the seconds pendulum derived from the *Journal des Sçavans*.[34] And, crucially, the following year, on Friday 6 August 1677 while staying in Paris, he read a review of Huygens' *Horologium oscillatorium* in the *Journal des Sçavans* and noted the following in his journal:

> The length of a pendulum of seconds according to Mr. Hugenius's computation Jour Scav: 1 Jan. 74, being 881 demy lines, or which is the same, 3 foot 8 $^1/_2$ lines of the foot of Paris ... And the English yard, supposeing it to be [ ] lines of the Paris foot will be [ ] of 1000 of a pendulum of seconds. (Lough, 1953, p. 160)[35]

This seems to have spurred Locke into action, for the very next day he noted down the French units of length and their relation to each other and proposed a unit of measure which he called the philosophical foot, a thousandth part of which is a gry: 'the philosophical foot being divided into 1000 parts which one may call grys' (Lough, 1953, p. 161). A philosophical foot is one third of the length of a seconds pendulum in Paris as determined by Huygens. It was equivalent to Huygens' hour foot. As for comparative measures, the Paris foot was equivalent to 981 grys less $\frac{1}{3}$ of a gry (Lough, 1953, p. 161). Thus, Locke's philosophical foot and gry were based upon the length of Huygens' seconds pendulum as reported in the *Horologium*. Yet, in contrast to the Carolina measures of length, it was not fully decimalised relative to the length of the seconds pendulum. Where the drom was to be divided into ten eps, ten eps into ten furs and ten furs to ten grys, Locke's new measure was a decimalized measure of one-third of the length of the seconds pendulum. The upshot was that Locke's new gry was one-third the length of the Carolina gry.

That very day he visited the leading Parisian instrument-maker Michael Butterfield and while there he may well have ordered a ruler marked out according to his philosophical foot. For, two-and-a-half months later Locke took receipt of a brass ruler made according to the philosophical foot. He records in his journal beside the marginal entry 'Pes philosophicus': 'Mr. Butterfield brought me home my rule'. Then follows a list of what are probably markings on the ruler: 'V the universall foot, P pes parisiensis, D —— of Denmark, L of Leyden, E of England, P. R. Palma Romana' (Lough, 1953, p. 180).[36] The fact that his marks include 'D —— Denmark' suggests that Locke was in dialogue with the Danish astronomer Ole Rømer on questions of metrology. Rømer resided in Paris, having been brought there in 1672 by the leading French astronomer Jean Picard.

Locke returned to his unit of measure again on 29 January 1678 while still in Paris. He now worked out how many grys made up the different feet that were apparently marked on his ruler. The length in grys of the foot of Leiden is 948, of Paris 980, of Denmark 955, of England 920, and the Palma Romana 672.[37] More importantly, he spells out the decimal subdivisions of the philosophical foot and compares the gry to the English inch.

> A pendulum of seconds being divided into 3 equall parts, each of them makes that which may be cald the philosophicall or universall foote, the 10th part of which foot I call an inch, the 10th part of that inch a line, & the 10th part of a line a gry: soe that the English foot is 9 inches 2 lines 0 grys of the philosophicall foot & consequently the English inch 7 lines & 6 $\frac{2}{3}$ grys. (Lough, 1953, p. 185)

A few months later, on 13 May 1678, he returned to Butterfield's house where he examined the Parisian measure of length called the aune: 'Aune de Paris contient 3 pied 8 pous du Roi. This measure taken chez Butterfeild upon a tradesman aune' (Lough, 1953, p. 195, corrected). Then on 2 July 1678 Locke packed away his brass ruler along with other things, including a manuscript entitled 'Essay de Intellectu', that is, a draft of the *Essay*, and set off on another trip around France (Lough, 1953, p. 202). On returning to Paris he continued to make observations concerning the Paris foot, and in early March 1679 compared it with the English foot in the company of the astronomer Adrien Auzout (Lough, 1953, p. 259). In fact, this is the earliest sign in Locke's journal that he was beginning to have misgivings about the length of the seconds pendulum at different latitudes. This can be inferred from the fact that he had written to Robert Hooke at the Royal Society via his friend Dr John Mapletoft, probably in late February 1679, about the length of the pendulum in

[30] Lough (1953, p. 14).
[31] Bodl. MS Locke f. 1, p. 47; see also pp. 33 and 44, none of these measures appear in Lough (1953).
[32] See, for example, Bodl. MS Locke f. 1, pp. 50, 54, 55 and 56.
[33] Lough (1953, pp. 22, 23, 42, 46, 67, 114, 180) and Bodl. MS Locke f. 1, pp. 146–7 for notes on classical measures. Neither Lough nor Dewhurst chose to transcribe all of Locke's journal entries for 'Mensurae'.
[34] Bodl. MS Locke f. 1, p. 262: 'pendul: Une pendule d'un filet de 9 $^1/_4$ poulces de longueur marquera les demy secondes comme un filet de 37 poulces marque les seconds dont les 60 sont la minute. Journal des Scavants 24 May 66 p. 300. 12° Amsterdam 66 $\overline{611}$′, not in Dewhurst (1963) or Lough (1953). See also Lough (1953, p. 157): '6 Inch English make of the French 5 $\frac{7}{12}$ inches'.
[35] Blanks were not filled in by Locke. Lough has '888' where the MS has '881' demy lines. See Bodl. MS Locke f. 2, p. 215.
[36] Locke gave his ruler to Newton just before his death. See Locke to Peter King, 4 and 25 October 1704 (OS), Locke (1976–1989, Vol. 8, p. 415).
[37] Lough (1953, p. 185).

London, for, Hooke records in his journal on 1 March, ‘At Dr. Mapletofts. Locks Letter about Length of Pendule’.[38]

A reply was quickly forthcoming, for when Locke copied into a notebook (now Bodl. MS Locke c. 42) a list of measures in French given to him by Picard in March of that year,[39] he added a note that provides the first hint of a reservation concerning Picard’s estimate of the length of the English foot in relation to the French:

> And yet Mr Hooke sends me word by Dr Mapletoft that a pendule of seconds is 39 $\frac{1}{4}$ inches from the center of vibration to the center of the ball & here to fore Mr Shotgrave[40] told me it was 39 $\frac{2}{10}$ inches. Soe that either our pendule in England is longer then theirs here <at Paris> or the foot we measure by in England is shorter then what they take it to be at Paris JL[41]

It is quite likely that Locke received the list of measures from Picard on 17 March 1679, for that was the day he visited Picard’s residence and had him check his universal foot:

> I examind my Universal foot on which is the compas of proportion, at Mr. l’Abbé Picar’s & he found it just. He also told me that a Pendulum of seconds conteind of our English measure 39 $\frac{1}{8}$ inches, of the Paris measure 36 pouces 8 $^1/_2$ lines or 36 $\frac{708}{1000}$ pouces. (Lough, 1953, p. 261)

However, it is not entirely clear what instrument Locke is referring to here. On the one hand, he may refer to his brass ruler adding the detail that a compass of proportion is somehow mounted on it. On the other hand, ‘universal foot’ may refer to a universal mounting on which a sector (*compas de proportion*) was mounted. An instrument of this type made by Butterfield is to be found the collections of the Museum of the History of Science, Oxford.[42] If this is the case, Locke is referring to a second instrument, different from his brass rule.[43]

In addition, he revisited the issue of the relative lengths of the Parisian and English feet that he had earlier discussed with Auzout: ‘The foot of Paris being divided into 1440, i.e. tenths of a line, the English foot conteines of them 1351’ (Lough, 1953, p. 261). And he also recorded some advice from Picard on the fastening of pendulums to walls rather than the floor. Later, at Rømer’s lodging he tested the effect of lengthening a seconds pendulum:

> A[t] Mr Romers chamber in the Observatoire at Paris we found that the pendulum <of seconds> being lengthened 1 line lost one second in about $^1/_4$ hower.[44]

He left for England six weeks later on 30 April 1679, accompanied by Rømer,[45] who had been charged by the Académie des Sciences with the task of determining the precise length of the seconds pendulum in London and the relative length of the English foot.[46] (Incidentally, Rømer would return (via Paris) to his native Denmark just four years later in 1683 and oversee there the introduction of a new system of weights and measures and in 1699 reform the Danish calendar. The new Danish standard of length adopted in 1683 was also based on the seconds pendulum.)

Ten days after returning to England Locke received a letter from his Parisian friend Nicolas Toinard that contained some more potentially unsettling news.[47] Toinard wrote:

> Mr Richer who paid me the honour of coming to me recently, persisted in saying that the seconds pendulum is shorter by a line and $^1/_4$ at Cayenne than at Paris, although I objected to him that Mr Picard had not found any difference in five stations from Copenhagen to Montpellier. Cayenne, however, is 4° 56′ north and 3 hours 28 minutes to the west of the observatory in Paris which is [latitude] 52°. (Toinard to Locke, 20 May 1679, Locke, 1976–1989, Vol. 2, p. 17)[48]

If Richer’s measurements were correct, then the prospects of using the philosophical foot as a universal standard of length would be scuppered. Interestingly, Hooke had expressed this very fear to Newton as a result of learning of Halley’s observations during his trip to St Helena: ‘[t]his will spoyle the Universall Standard by the Pendulum and the Æquality of Pendulum Clocks carryed from one climate to another’.[49] Meanwhile, Rømer had set about measuring the relative length of a seconds pendulum in London to that of Paris. He seems to have made more than one attempt as we can see from the corrections Locke made in his journal entry on ‘pendule’: ‘Thursd. 15 May Mr Romer tells me that the pendule here is ~~exactly the same that~~ <about $\frac{1}{6}$ of a line longer than> at Paris and that <18 May>[50] it is of our English measure 39 $\frac{1}{8}$ inches’.[51]

Locke, initially at least, seems to have been nonplussed. He wrote to Boyle a month later (16 June 1679 (OS)) concerning a case of unusually long finger nails and toe nails on a boy that he had seen back in May 1678 at the Hôpital de la Charité in Paris: ‘The longest of all was that on the middle finger of the right hand, ... which was three[52] inches and nine grys long’ (Locke, 1976–1989, Vol. 2, p.

[38] Hooke (1968, p. 401). Locke had written to Hooke a few months earlier, around December 1678, see Birch (1756–1757, Vol. 3, p. 448). Hooke was keenly interested in the possibility of variation in the seconds pendulum and was experimenting with pendulums at different elevations. He does not appear to have related the variation in the length of the pendulum to the shape of the Earth.

[39] See Lough (1953, p. 261 n. 4).

[40] I.e. Richard Shortgrave.

[41] Bodl. MS c. 42, part 1, p. 88. ‘< ...>’ indicates interlineation. The reference to ‘here at Paris’ confirms that this was written before Locke left for England. The letter from Mapletoft is no longer extant.

[42] Surveyor’s Sector by Butterfield, c. 1700, Inventory Number 46250: http://www.mhs.ox.ac.uk/collections/imu-search-page/record-details/?thumbnails%3don%26irn%3d2822%26TitInventoryNo%3d46250 (accessed 23 September 2016).

[43] I am grateful to Jim Bennett and Anthony Turner for pointing out to me the ambiguities inherent in Locke’s description of his instrument.

[44] Bodl. MS Locke c. 42, part 1, p. 214. Patrick Connolly alerted me to this reference.

[45] Needless to say Locke and Rømer discussed the speed of light. See Lough (1953, p. 274). Locke had earlier noted Rømer’s estimate of the speed of light as discussed in the *Journal des Sçavans*, December 1676. See the entry for 19 July 1677, Bodl. MS Locke f. 2, p. 262, omitted in Lough.

[46] See Dew (2012, pp. 248 and 251 n. 15). It is conceivable that Hooke’s communication with Locke played an indirect role in the Académie’s decision, though no evidence on this has come to light.

[47] For a helpful discussion of Locke’s correspondence with Toinard, see Di Biase (2013).

[48] All translations are my own. Jean Richer’s observations were published in his *Observations astronomiques et physiques faites en l’isle de Caïenne* which carries the date 1679 on the title page, though they were not widely available in print until 1693. See Richer (1693 [1679]).

[49] Hooke to Newton, 6 January 1678/9 (OS), Newton (1959–1977, Vol. 2, p. 310). The date of this letter is probably few months before Locke heard from him via Mapletoft. Newton appears not to have heard of Richer’s observations until 1683 at the earliest. See Newton’s Wastebook, Cambridge University Library MS Add 4004, fol. 101v, transcribed in Cook (1998, p. 116) which mentions Varin and Deshayes’ pendulum measurements on the Ilse of Gorée of 1683 in the same entry.

[50] Following an illegible deletion.

[51] Locke’s journal for 1679, British Library Add. MS 15642, pp. 94–5. Rømer also determined the relative measure of the philosophical foot and related this finding to Locke who recorded on 21 May (OS): ‘he [Rømer] tells me that our English foot is 1:920 [grys] of the universal foot’, Bodl. MS Locke f. 28, p. 116. This confirmed the comparison that Locke had made the previous year in Paris.

[52] ‘Three’ is an error, perhaps an error of transcription on the part of Thomas Birch who first published the letter. The original letter is no longer extant. Locke’s journal and the published version of his account both indicate that the length is ‘a little more than four inches of our *English* foot’, Locke (1697, p. 596).

38).[53] Realising that he ought to explain his unit of measure he concludes as follows:

> Before I conclude, I must not forget to tell you, that the measure I made use of was the philosophical foot, *i e.* $\frac{1}{3}$ of a pendulum of seconds, which I divided thus: the foot into ten inches, the inch into ten lines, the line into ten grys; so that a gry is $\frac{1}{1000}$ part of PP[54]; which measure, whatever it be for other purposes, I thought the fittest for philosophical communications, and therefore made use of it in this and several other occasions. But I have troubled you too long already to mention here the conveniencies of this foot, and (as I think) of the way of dividing it by decimals. (Locke, 1976–1989, Vol. 2, p. 39)

Clearly he still had confidence in his philosophical foot and its one thousand grys. Among the 'conveniencies' of Locke's gry was the manner in which it allowed extremely fine discriminations in differences of length. This was Locke's attempt at a practical solution to the fourth problem of measurement that he had discussed earlier in the decade in the drafts to the *Essay*.

Yet there is evidence that the 'Richer result' had begun to niggle. In September he must have asked Rømer his view of the matter, for Rømer replied from Paris where he had returned after his trip across the Channel with Locke:

> As to the question you ask me about the pendulum, I have not yet wholly satisfied myself, let alone you, as to what the right answer is. It is certain at any rate that it is insensibly longer in your country, by, I think, a 6th or 7th part of a line, assuming that the uncertainty of the universal foot resulting from these experiments does not exceed the 20th part of a line. (Rømer to Locke, 15 September 1679, Locke, 1976–1989, Vol. 2, p. 92)[55]

Nevertheless, Locke persevered with his standard of length and we find him using it again the following May when reporting to Toinard on some massive hailstones that had fallen in London, one of which was 420 grys in circumference (20 May 1680 (OS), Locke, 1976–1989, Vol. 2, p. 176).[56] He also used the gry to establish the precise dimensions of a document cabinet that he designed, a proto-type of which he showed to Rømer. It was a ten-by-ten set of pigeonholes and it piqued the interest of Toinard to whom Locke sent the exact dimensions.[57]

4. Locke and longitude

The variability of the seconds pendulum from one latitude to another was one thing, the utility of the pendulum as a timekeeper and, in particular of the pendulum clock, was quite another. One reason for a growing confidence in the pendulum as a measure of duration was the steady stream of important results issuing from the work of Picard. Picard had been set the task of revising the map of France and to do so he needed accurate measures of longitude. This was achieved using a method developed by Cassini in Paris. It involved setting (by astronomical observations) two pendulum clocks to local time at different locations and recording the time at those locations of the same immersion into or emersion from the shadow of Jupiter, of the moon closest to Jupiter.[58] On 20 September 1679 Toinard wrote to Locke with the results of Picard and Rømer's latest determination of the longitude at Brest, the most westerly town on the French Atlantic coast. They found a difference of 27 min and 31 s between Brest and Paris and this was duly reported to Locke.[59] This figure differed from the most recent map of France by 5 min and 9 s which meant that a significant revision of existing maps was required, as Toinard pointed out to Locke.

It was this sort of detail that fascinated Locke and which he went out of his way to collect. Throughout his journal, for instance, there are occasional entries for the latitude of cities and landmarks in France.[60] The salient point is, of course, that none of this work could be done if the pendulum was not a reliable timekeeper. An indication of the extent to which Locke followed the details of Picard's findings is found in his attitude to one of Picard's editorial projects, *La connoissance des temps*, a kind of French ephemerides that supplied all sorts of useful data including advice on the use of pendulums. This publication first appeared in 1679 and Locke procured a copy. He was keen to get the second issue and wrote to Toinard concerning it:

> Seeing that the pamphlet entitled *La connoissance du temps* is so useful I wonder why we are given no hope of having it beyond this year. But that is how mankind is usually treated; the more useful anything new is the more difficult it is to make it available. (Locke to Toinard, 10 June 1680 (OS), Locke, 1976–1989, Vol. 2, pp. 194–5)

In the event, Locke did procure the second issue as well as two others,[61] so it is worth turning to the first two issues to see what they have to say about the longitude of Brest. The 1679 issue has Brest at longitude 0 h, 22 min west of Paris: the 1680 issue has the revised figure of 0 h, 28 min, reflecting the new finding of Picard and Rømer. It is unlikely that this point was lost on Locke because he annotated the table of longitudes in both Picard (1679) and Picard (1680) (see Fig. 1).

5. Locke's *Essay* and the standard of length

It seems that it took at least another eight years before Locke again thought seriously about the gry. While he was in exile in the Netherlands in 1688 he reviewed a very technical work in natural philosophy in the *Bibliothèque universelle et historique*, perhaps at the behest of the editor of the journal, his friend Jean Le Clerc. The book was none other than Isaac Newton's *Philosophiae naturalis principia mathematica* (hereafter *Principia*) which had been published in Latin in 1687. In his summary of Book Three of the *Principia* Locke relates the following claim of Newton:

[53] For Locke's original journal entry of 24 May 1678 on the horny excrescences, see Dewhurst (1963, pp. 122–4). The entry also includes a description of an oval-shaped stone removed from an eleven-year old boy 'whose circumference the long way was 450 gr: and girt crosse above 360gr', Dewhurst (1963, p. 123).

[54] I.e. Pes philosophicus.

[55] Copied by Locke into Bodl. MS Locke d. 9, p. 141.

[56] See also Locke to Toinard, 10 June 1680 (OS), Locke (1976–1989, Vol. 2, p. 194).

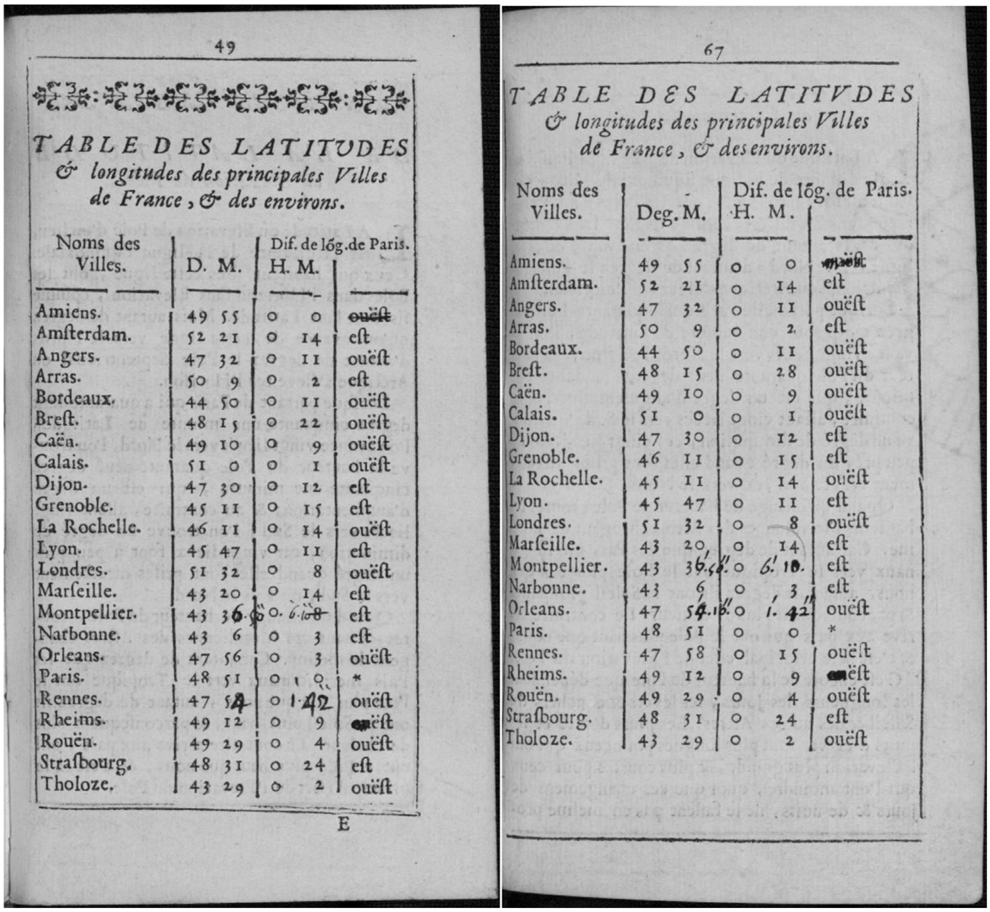
[57] See Locke to Toinard, 6 June 1679 (OS), Locke (1976–1989, Vol. 2, p. 31) and 13 December 1680 (OS), Locke (1976–1989, Vol. 2, p. 315). On 1 August (OS) Locke sent Toinard and Rømer '1 box universall foot' each. These are most probably folding boxwood rulers one philosophical foot in length and marked with the English foot. See British Library Add. MS 15642, p. 126 and Locke to Toinard, 15 August 1679 (OS), Locke (1976–1989, Vol. 2, p. 72) where they are described as 'Pied Universel et d Angleterre en buis plicatil'.

[58] Locke viewed the moons of Jupiter at the Observatoire de Paris with Giovanni Domenico Cassini on 7 October 1677, see Lough (1953, p. 176). For Locke's diagram of Rømer's mechanical model of the orbits of the moons of Jupiter, see British Library Add. MS 15642, p. 152, Bodl. MS Locke c. 42, part 1, p. 200 and Lough (1953, p. 263).

[59] See Toinard to Locke, 20 September 1679, Locke (1976–1989, Vol. 2, p. 100).

[60] For Montpellier, see Lough (1953, p. 112): 'Montpellier is about $43^1/_2$ d north Latitude Dr. Jolly' and for Paris, see Lough (1953, p. 267). For the coordinates of cities and landmarks in Canada, see Lough (1953 pp. 270–1).

[61] See Harrison and Laslett (1971, #836a). See also Bodl. MS Locke f. 28, p. 156.



49

TABLE DES LATITUDES
& longitudes des principales Villes de France, & des environs.

Noms des Villes.	D. M.		Dif. de lóg. de Paris. H. M.		
Amiens.	49	55	0	0	ouëſt
Amſterdam.	52	21	0	14	eſt
Angers.	47	32	0	11	ouëſt
Arras.	50	9	0	2	eſt
Bordeaux.	44	50	0	11	ouëſt
Breſt.	48	15	0	22	ouëſt
Caën.	49	10	0	9	ouëſt
Calais.	51	0	0	1	ouëſt
Dijon.	47	30	0	12	eſt
Grenoble.	45	11	0	15	eſt
La Rochelle.	46	11	0	14	ouëſt
Lyon.	45	47	0	11	eſt
Londres.	51	32	0	8	ouëſt
Marſeille.	43	20	0	14	eſt
Montpellier.	43	36	0	8	eſt
Narbonne.	43	6	0	3	eſt
Orleans.	47	56	0	3	ouëſt
Paris.	48	51	0	0	*
Rennes.	47	58	0	1·42	ouëſt
Rheims.	49	12	0	9	ouëſt
Rouën.	49	29	0	4	ouëſt
Straſbourg.	48	31	0	24	eſt
Tholoze.	43	29	0	2	ouëſt

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67

TABLE DES LATITUDES
& longitudes des principales Villes de France, & des environs.

Noms des Villes.	Deg. M.		Dif. de lóg. de Paris. H. M.		
Amiens.	49	55	0	0	ouëſt
Amſterdam.	52	21	0	14	eſt
Angers.	47	32	0	11	ouëſt
Arras.	50	9	0	2	eſt
Bordeaux.	44	50	0	11	ouëſt
Breſt.	48	15	0	28	ouëſt
Caën.	49	10	0	9	ouëſt
Calais.	51	0	0	1	ouëſt
Dijon.	47	30	0	12	eſt
Grenoble.	46	11	0	15	eſt
La Rochelle.	45	11	0	14	ouëſt
Lyon.	45	47	0	11	eſt
Londres.	51	32	0	8	ouëſt
Marſeille.	43	20	0	14	eſt
Montpellier.	43	36′.50″	0	6′ 10.	eſt
Narbonne.	43	6	0	3	eſt
Orleans.	47	54′.16″	0	1′. 42″	ouëſt
Paris.	48	51	0	0	*
Rennes.	47	58	0	15	ouëſt
Rheims.	49	12	0	9	ouëſt
Rouën.	49	29	0	4	ouëſt
Straſbourg.	48	31	0	24	eſt
Tholoze.	43	29	0	2	ouëſt

Fig. 1. Locke's annotations to his 1679 and 1680 editions of *La connoissance des temps*, Bodleian Library Shelfmark Locke B 6.3/1, p. 49 and Locke B 6.3/2, p. 67. (Used with permission of the Bodleian Libraries, University of Oxford.)

The Earth is 85,200 Paris feet or 17 miles higher at the Equator than at the Poles.[62] For otherwise the Sea filling from Poles to the Equator, would inundate the whole surface of the Globe. The force, which proceeds from the diurnal motion and away from the centre, of the parts of the Earth at the Equator is in relation to its gravity[63] as 1 to 290 $\frac{4}{5}$. The shape of the other planets is somewhat close to that of the Earth.

Gravity at the Pole is to gravity at the Equator as 692 to 689. Hence it is that the longitude [sic] found by means of a pendulum which makes its vibrations at each second at Paris, latitude 48° 45′, is 3 feet and $\frac{17}{24}$ inches and surpasses the longitudes [sic] found in the isle of *Gorée* at [latitude] 14° 15′ by $\frac{81}{1000}$, at Cayenne in Guinea, latitude of 5°, by $\frac{89}{1000}$, and at the Equator by $\frac{90}{1000}$ inches.[64] (Locke, 1688, pp. 446–7)

The second paragraph here is somewhat garbled. Newton, and, therefore we take it Locke, was not speaking about longitude in this context. Rather the point at issue is the length of the seconds pendulum. Locke could hardly have missed the import of Newton's claims. Newton, in his most impressive book, had taken Richer's observations (and the later observations of Varin and des Hayes on the isle of Gorée in 1682[65]) seriously and had clearly seen their implications for his (Newton's) view of the shape of the Earth and the variation between gravity at the Equator and at the poles. If Newton were correct, it would imply that Locke's gry is not a universal measure because the length of the pendulum will vary with latitude. If he had earlier embraced the scepticism of Toinard and Picard toward Richer, Newton's treatment of the subject forced a rethink.

All of this happened while Locke was writing Book Four of the *Essay*. Now, surprisingly, Locke's only mention of the gry in the

[62] Quoting Newton (1687, p. 424).

[63] The text has 'poids' but Newton (1687, p. 422) has 'vim gravitatis'. Clearly gravitational force rather than weight is in view here. This may reflect Le Clerc's misunderstanding of Locke's paraphrase (see following note).

[64] It may be that Locke was extracting Newton's Latin at this point in the review and that Le Clerc misunderstood Newton's use of the terms *longitudo* and *longitudines*, thinking that the passage refers to longitude when it refers to the length of seconds pendulums: *longitudo* in Latin means length. Newton's claim can be paraphrased as follows: The gravity at the pole is to the gravity at the Equator as 692 to 689. As a result, the length of the seconds pendulum at Paris, latitude 48° 45′, is 3 feet $\frac{17}{24}$ inches and surpasses the lengths of the seconds pendulums at the isle of Gorée, latitude 14° 15′, at Cayenne in Guiana, latitude 5°, and at the Equator by $\frac{81}{1000}$, $\frac{89}{1000}$, and $\frac{90}{1000}$ inches respectively. See Newton (1687, p. 425) and Newton (1999, p. 827).

[65] See Newton (1999, pp. 829–30) for Newton's discussion of the French experiments on variations in the seconds pendulum in the second edition of the *Principia*. For Varin and des Hayes' expedition, see Dew (2010). Another to take this passage in the *Principia* seriously was David Gregory, Savilian Professor of Astronomy at Oxford. He mentions Richer's finding at Cayenne in his Oxford lecture on the shape of the Earth on 19 October 1693. See Aberdeen University Library MS 2206/3/3, fol. 73v.

Essay is a somewhat gratuitous reference in the rather unlikely chapter in Book Four on 'Our knowledge of the existence of a God'. It is followed immediately by a footnote entry that supplies the reader with the definition of a gry. The reason for this humble location of the gry in the *Essay* becomes clear when we see that Locke added a crucial new qualification to his definition of the gry:

> A Gry is $\frac{1}{10}$ of a line, a line $\frac{1}{10}$ of an inch, an inch $\frac{1}{10}$ of a philosophical foot, a philosophical foot $\frac{1}{3}$ of a pendulum, whose Diadroms, in the latitude of 45 degrees, are each equal to one Second of time, or $\frac{1}{60}$ of a minute. I have affectedly made use of this measure here, and the parts of it, under a decimal division with names to them; because, I think, it would be of general convenience, that this should be the common measure in the Commonwealth of Letters. (*Essay* IV. x. 10 n. a [underlining added])

The qualification, of course, is 'in the latitude of 45 degrees'. This did not appear in the definition Locke gave to Boyle in 1679 or in the initial definition given in his journal. What are its implications?

First, it is almost certain, coming as it did around the time that Locke wrote the *Principia* review, that he had seen the implications of Newton's claims and therefore Richer's observations and decided to err on the side of caution: if they are correct, the philosophical foot will vary with latitude and Locke's own ruler is not based on a natural standard! Second, there is the question of why Locke chose latitude 45° for the standard. It was a natural choice given that it is the midpoint between the equator and the poles, though it was, for an Englishman, highly impractical, for no part of England crosses the 45th parallel. If one were to calibrate a seconds pendulum and then determine the length of the philosophical foot and gry, one would have to go to the Continent. Whatever the case, it is worth noting the irony in the fact that exactly one hundred years after the publication of the *Essay*, the first proposal in revolutionary France for a new system of weights and measures advocated using a seconds pendulum calibrated at latitude 45°, something that they also recommended to the English.[66] Third, and perhaps more disconcerting, are the implications for Locke himself. For what we know about his ruler is that it was made and checked in Paris which is not on the 45th parallel at all. Nor does the 45th parallel pass through the Netherlands, so it seems unlikely that Locke had a new ruler constructed in the last years of his exile there.

What then does Locke have to say about the seconds pendulum in the *Essay*? In the chapter on 'Of Duration, and its simple Modes' Locke recycles his sceptical considerations about the accuracy of the seconds pendulum as a measure of a unit of time that he expressed nearly twenty years earlier in Draft B. Thus, in his treatment of problem two above he does not temper his reservations about their accuracy:

> Duration in it self is to be considered, as going on in one constant, equal, uniform Course: but none of the measures of it, which we make use of, can be known to do so; nor can we be assured, that their assigned Parts or Periods are equal in Duration one to another ... and though Men have of late made use of a Pendulum, as a more steady and regular Motion, than that of the Sun, or (to speak more truly) of the Earth; yet if any one should be asked how he certainly knows, that the two successive swings of a Pendulum are equal, it would be very hard to satisfie himself, that they are infallibly so. (*Essay* II. xiv. 21)[67]

This is because we cannot be sure that the pendulum itself is operating uniformly or that changes in the medium in which it swings are not affecting it. This is in spite of the fact that Locke was fully apprised of the great utility of the pendulum clock in the determination of longitude. He does, however, pick up the point he had made in Draft B about the concurrence of probable reasons:

> All that we can do for a Measure of Time, is to take such as have continual successive Appearances at seemingly equidistant Periods; *of* which *seeming Equality*, *we have no other measure*, *but* such as *the train of our own Ideas* have lodged in our Memories, with the concurrence of other probable Reasons, to perswade us of their Equality. (*Essay* II. xiv. 21 [underlining added])

The point is that coordinating the train of thoughts in our own mind with the swing of the pendulum and the diurnal rotation of the Earth is sufficient 'to perswade us of their Equality'. What is interesting here is the manner in which Locke has continued to tie his theory of ideas to his adumbration of a solution to the coordination problem: the concurrence of probable reasons provides grounds for trusting the seconds pendulum as a measure of time and one of those grounds is the succession of ideas in our own minds.

As for the problem of comparative measures for the sensible qualities, Locke develops the sketchy treatment in Drafts A and B in the first edition of the *Essay*. For, he now sets out the problem in terms of a corpuscular theory of matter:

> For those other simple *Ideas*, being appearances or sensations, produced in us, by the Size, Figure, Number, and Motion of minute Corpuscles singly insensible, their different degrees also depend upon the variation of some, or all of those Causes; which since it cannot be observed by us in Particles of Matter, whereof each is too subtile to be perceived, it is impossible for us to have any exact Measures of the different degrees of these simple *Ideas*.

He then gives a speculative explanation of degrees of whiteness:

> For supposing the Sensation or *Idea* we name *Whiteness*, be produced in us by a certain number of Globules, which having a verticity about their own Centres, strike upon the *Retina* of the Eye, with a certain degree of Rotation, as well as progressive Swiftness; it will hence easily follow, that the more the superficial parts of any Body are so ordered, as to reflect the greater number of Globules of light, and to give them that proper Rotation, which is fit to produce this Sensation of White in us, the more White will that Body appear. (*Essay* IV. ii. 11)

Then, after distancing himself from a commitment to any particular physical theory of light he goes on to reiterate the point about our lack of measures for comparative qualities:

> Not knowing therefore what number of Particles, nor what Motion of them is fit to produce any precise degree of *Whiteness*, we cannot demonstrate the certain Equality of any two degrees of *Whiteness*, because we have no certain Standard to measure them by, nor Means to distinguish every the least real difference. (*Essay* IV. ii. 13)

Locke seems persuaded of the likelihood that it is not the phenomenal qualities of our idea of whiteness that prevent us from having accurate comparative measures, but our lack of epistemic access to the underlying, yet measureable, primary qualities of corpuscles, such as motion, that give rise to our idea of whiteness. This is a major development on the muted particulate matter

[66] See Miller (1790, pp. viii–ix). This is not to claim that no one apart from Locke suggested the 45th parallel standard before the French Revolution.

[67] Another variant of this passage is found in Draft C, II. 17, 28–9.

theory that is to be found in the early Drafts.[68] It is also of a piece with Locke's broader treatment of sensible or secondary qualities throughout the *Essay*.

6. After the first edition of the *Essay*

The *Essay* appeared in December 1689 and Locke met Newton very soon after the event: some time before mid-February 1690. They soon struck up a friendship and in 1691 Newton presented Locke with a corrected copy of his *Principia*. Ever on the lookout for constants and measures, Locke was struck by Newton's estimate of the speed of sound. In the first edition of the *Principia* Newton had set parameters for the speed of sound as somewhere between 920 and 1085 English feet *per* second. By 1689 he had revised this to 984 to 1094 English feet *per* second. We know this because it is among the corrections that he gave to Fatio de Duillier and which Fatio passed on to Huygens.[69] Newton kept on experimenting on this problem and by 1691 he had revised his upper parameter again to 1111 and his latest calculations were included in the corrected edition that he gave Locke. Locke noted this estimate in his notebook in 1691.[70] In subsequent years he recorded other natural philosophers' estimates of the speed of sound in the same notebook.[71] Locke was clearly aware that the determination of the speed of sound was still an open question. He was content merely to record the latest estimates and leave it at that. The salient point, however, is that, as was the case with the determination of longitude, Newton's experiments contrived to determine the speed of sound used pendulums of different sizes (not pendulum clocks) to measure time.[72] Around about the same time he made another notebook entry (in Bodl. MS Locke d. 9, p. 141) under the heading 'Pendulum' summarizing Newton's claims in the *Principia* about the different lengths of the seconds pendulum at Cayenne and the isle of Gorée. This was the very point that he earlier summarized in the original *Principia* review of 1688.

Interestingly, it was probably around this time, that is, the early 1690s, that Locke came into possession of another work that presented new determinations of longitude using the method of Cassini. This was the second of Newton's editions of Varenius' *Geographia generalis*, which had been published in Cambridge in 1681.[73] Like Locke, Newton was fascinated by the new developments in special geography. He probably taught geography at Cambridge (it was included in the statutes for the Lucasian chair of mathematics and was taught by his predecessor Isaac Barrow).[74] Furthermore, he had the requisite skills to make a contribution to the field. It is most interesting, therefore, to compare the first edition, Varenius (1672), with the second 1681 edition. In the section on the discovery of longitude in the first edition there is no mention of the use of pendulum clocks or of the timing of the occultations of the moons of Jupiter.

By the second edition all this had changed: Newton had assimilated the new French techniques and discoveries and, apparently, had used them to improve on and update the table of determinate latitudes and longitudes that was originally included by Varenius himself. Thus, the second edition of Newton's Varenius includes two new sections outlining the new methods for determining longitude. The first is *Modus quintus per Planetas Joviales* and the second *Modus sextus per Horologium Automaton* (Varenius 1681, pp. 421–3).[75] Neither of these methods was present in the first Cambridge edition.[76] This then is part of the backstory of how Newton came to appreciate the significance of Richer's and Varin and des Hayes' claims about the variation of the seconds pendulum close to the Equator in the first edition of the *Principia*. Clearly, by the early 1680s Newton was fully apprised of these developments in special geography and soon came to see their implications for his account of the shape of the Earth and the nature of terrestrial gravity.[77]

Turning back to Locke, his interest in Varenius was almost certainly inspired by more than the parallels between Newton's second edition and the work of Picard, for, Varenius's book (Varenius, 1650), is cited three times in Boyle's *Spring of the Air* and, while it does not style itself as a Baconian natural history, its survey of special geography is an extremely close match with Boyle's 'General heads for a natural history of a countrey, great or small'.[78] In particular, both Boyle and Varenius are concerned with the nature of the air and its variations, winds, etc. In fact, the project of special geography in England was sometimes styled as the project of natural history.[79] Needless to say, it is this broader methodological framework to which Locke was committed, and to which he made a modest contribution, that accounts for Locke's interest in Newton's Varenius. It is hardly surprising then, to find Locke resuming his daily weather records in 1692.[80]

The central importance of pendulums and pendulum clocks in the measurement of the speed of sound and the determination of longitude must have reinforced Locke's view that, while there were problems with calibration, the pendulum had emerged as the most important means of measuring duration. Yet the question as to the status of Richer's observations appears to have remained an open one for Locke.

In 1697 Locke published his 'An account of one who had horny excrescencies or extraordinary large nails on his fingers and toes' in the *Philosophical Transactions* in which, as we have seen, he measured the horny excrescencies using the gry.[81] His definition of the gry here is similar to that which he sent to Boyle in 1679 and not the more qualified one found in the *Essay*. Moreover, Locke's measures of the horny excrescences were identical to those in his journal of May 1678. Thus, he was not using a unit of length determined at latitude 45°; he was not using his revised

[68] See Downing (2001) for further discussion of the matter theory in the Drafts of Locke's *Essay*.

[69] See Huygens (1888–1950, Vol. 10, p. 155).

[70] Locke's *Principia*, Trinity College, Cambridge, shelfmark Adv.b.1.6; Bodl. MS Locke d. 9, p. 83.

[71] In 1690, before Locke had received Newton's corrected *Principia*, he had noted Huygens' and John Flamsteed's measures for the speed of sound and the relevant page number in the *Principia* on the speed of sound, see Bodl. MS Locke c. 42, part 1, p. 149. He had also noted Huygens' comparison of the speeds of light and sound, see Bodl. MS Locke c. 42, part 1, p. 288. For Flamsteed's revised calculation, see the 1695 entry in Bodl. MS Locke d. 9, p. 294. Boyle had been asked by the Royal Society as early as 1661 to experiment on the speed of sound, see Birch (1756–1757, Vol. 1, p. 67).

[72] See Westfall (1980, pp. 455–6).

[73] Harrison and Laslett (1971, #3049). The book may well have been a gift from Newton himself.

[74] See Newton's 'Of educating youth in the universities' where he recommends that the lecturer in mathematics should '(if the Tutor be deficient) to instruct in the principles of Chronology & Geography', Newton (1962, p. 370).

[75] For a contemporary English translation, see Sanson (1682, Part I, pp. 302–3).

[76] It is worth pointing out that this textual material, buried as it is in Varenius' book, is authored solely by Newton and comprises a minor, though important part of the background to the writing of the *Principia*, background that was missed by Herivel (1965) and, as far as I can determine, by all subsequent Newton scholars.

[77] Though it must be admitted that the two editions of Newton's Varenius remain Cartesian works predicated on a spherical Earth set in a Cartesian vortex theory. For further discussion, see Warntz (1989).

[78] Boyle (1999–2000, Vol. 5, pp. 508–11).

[79] See the Preface to Richard Blome's *The Gentlemans Recreation*: 'the *Natural History* of the World ... is either *Universal*, and is termed *Cosmography*, being the Descriptions of the *World*; or Special', Blome (1686, sig. a1).

[80] See Locke (1705).

[81] Locke (1697).

philosophical foot. Had Locke been fully convinced of the 'Richer result' he may have qualified his account, pointing out the discrepancy. Then again, perhaps he was simply being pragmatic, realising that he could not take new measurements of the fingernails and toe nails and that any differences would be imperceptibly small.

Finally, to bring this long story to a close, Locke wrote to Toinard on 25 March 1698 (OS), and this time it is he who raises the question of pendulum calibration in Cayenne:

> I have read through with pleasure your friend's [Froger's] account[82] of his journey [to Cayenne]; I would ask him many questions if I were present, especially about the isle of Cayenne, where he stayed a very long time, e.g. whether they have observed the length of the pendulum in that island, which is so near the equinoctial line. (Locke, 1976–1989, Vol. 6, p. 358)

Does this imply that Locke was still not convinced by Richer's observations? We cannot be sure, but it does suggest that Locke regarded the question as still open. Sadly, however, it is here that the trail of evidence for Locke's views on the gry and the philosophical foot comes to an end.

7. Conclusion

What are we to make of all of this? Locke knew personally many of the leading innovators in metrology of his day, Picard, Rømer, Huygens and even Cassini. He saw and responded to the problem of standardization of measures. He saw and reflected upon the problem of circularity of coordination. He even appears to have glimpsed the solution of epistemic iteration in his conception of the concurrence of probable reasons in relation to the accuracy of the seconds pendulum.

Yet Locke lived in a time of metrological transition. Nothing served to bring this home to him more than his careful reading of Newton's *Principia* in 1688. Where in the early Draft B of his *Essay*, written in 1671, he had spoken freely of gravity as a property of material bodies, after reading the *Principia* the term was expunged from the *Essay*.[83] Where in the late 1670s he was quietly confident about his own universal standard measure for length, he now was forced to accept that it was probably no such thing. Rather than being integral to the *Essay*, the gry, in spite of all his efforts on its behalf, appears in a superfluous footnote, as if Locke felt he simply had to find a place for it. There is some irony then in the fact that, without any pretensions to contribute to mathematics, he effortlessly introduced the words 'billion' and 'trillion' into the English language in *Essay* II. xvi. 6 and yet the name for the unit of measure on which he had pinned his hopes, 'gry', never took off.

The *Essay* might well have been published without any mention of the gry, but the same cannot be said of the problem of the determination of a standard of measure for duration. On this point Locke's theory of the understanding and the succession of ideas in our own minds remained integral to his view of how we measure time. In the first instance, according to Locke, this is done reflecting on the train of ideas in our minds and only then do we turn to regular cycles such as the sun, the stars or pendulums.

By the end of his life Locke had come to accept that if there were natural measures for duration and length, humans remained ignorant of them. When it came to the measures of things, nature was reluctant to give up her secrets. Natural standards of measure did not yet fall within the compass of human understanding.

[82] François Froger (1676–1715), see Froger (1698).

[83] For example, compare Draft B §§70 and 73 with *Essay* III. ii. 3 and Draft B §80 with *Essay* vi. 35.

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