Estimating the age and affinities of *Homo naledi*

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Recent discoveries of more than 1500 hominin fossils from the site of Rising Star in the South African Cradle of Humankind, attributed to a new species (*Homo naledi*),[1] have attracted global interest. As yet no secure date for this extraordinary material has been obtained, and the relationship of this species to other Plio-Pleistocene taxa has been greatly debated in the media. Here I report results of morphometric analyses that may facilitate an assessment of the age and affinities of crania attributed to *H. naledi*.

The method is based on a least squares linear regression analysis of mean values of measurements for crania of 12 hominin species (Table 1), as published by Berger et al.[1] The analyses were performed to obtain standard errors of *m*-coefficients (se_m) in regression equations of the form $y = mx + c$, based on pairwise comparisons of cranial data, as described elsewhere for pairs of hominin specimens,[2,3] taking into account criticisms raised by Gordon and Wood[4].

The degree of scatter around a regression line of pairwise comparisons is quantified by the se_m statistic. Log transformed se_m values for conspecific pairs of modern vertebrates (as well as invertebrates) display a normal distribution with a mean value of -1.61,[5] which has been considered to be an approximation of a biological species constant (T) with a standard deviation of circa 0.1,[3] and which has been used to facilitate a mathematical (probabilistic) definition of a species[5].

It is of great interest to use this approach by comparing cranial measurements of *H. naledi* to those of other species listed in Table 1, using data published by Berger et al.[1] Log se_m Hn (*x* axis) values refer to results of pairwise comparisons when the measurements for *H. naledi* are on the *x* axis, and measurements for other taxa are on the *y* axis in regression analyses. Log se_m Hn (*y* axis) values refer to results of pairwise comparisons when the measurements for *H. naledi* are on the *y* axis, and measurements for other taxa are on the *x* axis. 'Log se_m mean' refers to the mean of these two values, and 'delta log se_m' refers to the difference between the two values, which can also be used to assess degrees of similarity or dissimilarity in the context of log se_m values.[3]

In the context of results reported for conspecific pairs of modern taxa, it is relevant to report two results from the current study. Firstly, *H. naledi* appears to be significantly different (dissimilar) from other species listed in Table 1, because all of the mean log se_m values listed in Table 1 are outside the 95% confidence limits around the mean value of -1.61 +/- 0.1 for conspecifics. Secondly, *H. naledi* appears to be most similar to specimens attributed to early *Homo*, notably *H. habilis*, and (to a lesser extent) *H. rudolfensis* and *H. erectus* (see numbers listed in bold in Table 1).

Table 1: Results of pairwise comparisons between cranial measurements of *Homo naledi* and corresponding measurements of other species

	Log se_m Hn (x axis)	Log se_m Hn (y axis)	Log se_m mean	Delta log se_m
Paranthropus aethiopicus	-0.852	-0.980	-0.916	0.128
P. boisei	-1.098	-1.067	-1.082	-0.031
P. robustus	-1.156	-1.119	-1.137	-0.037
Australopithecus afarensis	-1.110	-1.139	-1.124	0.029
A. africanus	-1.189	-1.142	-1.165	-0.047
A. sediba	-1.192	-1.120	-1.156	-0.072
Homo habilis	-1.326	-1.331	**-1.328**	0.005
H. rudolfensis	-1.200	-1.272	**-1.236**	0.072
H. erectus	-1.131	-1.256	**-1.193**	0.125
H. sapiens (Middle Pleistocene)	-1.062	-1.285	-1.173	0.223
H. sapiens (modern)	-1.102	-1.202	-1.152	0.100

Log se_m Hn (x axis) values refer to results of pairwise comparisons when the measurements for H. naledi *are on the* x *axis, and measurements for other taxa are on the* y *axis. Log se_m Hn (y axis) values refer to results of pairwise comparisons when the measurements for* H. naledi *are on the* y *axis, and measurements for other taxa are on the* x *axis. Log se_m mean refers to the mean of these two values, and delta log se_m refers to the difference between the two values. Relatively low log se_m values in bold reflect the fact that* H. naledi *appears to be most similar to specimens attributed to* H. habilis, H. rudolfensis *and (to a lesser extent)* H. erectus, *associated with ages in the order of 2 (+/- 0.5) mya.*

A conclusion from this analysis is that the claim that *H. naledi* represents a distinct species appears to be warranted, at least from cranial data. Without assuming that log se_m values can provide accurate dates, the results presented in Table 1 may be used to provide an estimate for the age of *H. naledi*, here considered to be in the order of 2 million years (+/- 0.5 years), recognising that the maximum age for *H. rudolfensis* is circa 2.5 mya, the age for African *H. erectus*

in this comparative study is circa 1.5 mya, and the age for *H. habilis* from sites such as Olduvai Gorge in Tanzania is circa 1.8 mya.

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