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How Accurately Could Early (622-900 C.E.) Muslims Determine the Direction of Prayers (Qibla)?

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Received: 20 December 2019; Accepted: 20 February 2020; Published: 25 February 2020

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Abstract: Debate has arisen over the ability of Muslim architects in the first two centuries of Islam to determine true qiblas accurately. Some believe that they had such a capability, while others think not. The argument could be more complex—perhaps some architects could, while others could not; perhaps their accuracy changed over time or over greater distances from qibla targets. Here, we investigated how the accurate qiblas of 60 mosques or related structures were, using data from Daniel Gibson's books and websites. Contrasts were drawn between theories that the qiblas of early mosques were—or were not—generally accurate. If one were to assume that Mecca was the only qibla, qiblas would not appear to have been accurate. However, if one were to assume that qiblas changed, it would be found that qiblas were accurate to plus or minus two degrees in over half of the cases and accurate within plus or minus five degrees in over 80% of cases. Accuracy was not related to distance but did appear to improve over historical time, while distance from the target cities and historical time were positively associated. The average qibla accuracy had a near zero error, with random variations on either side of that zero error. The overall distribution was not normal—kurtotic—because a greater accuracy was found than would have been expected with a normal distribution; however, the pattern deviated more from a uniform distribution than it did from a normal distribution. To try to synthesize the competing theories, we analyzed data for only 14 of the 60 mosques, those presumed to face towards Mecca, and we found fairly high degrees of qibla accuracy with nearly 43% of qiblas within two degrees of accuracy and nearly 80% within five degrees of accuracy. Comparing the accuracy of Meccan qiblas with other qiblas of the same century, we found no significant differences in azimuth errors. While some architects were more accurate than others, early Muslim architects seemed, in general, quite capable of placing qiblas with reasonable accuracy, even though their accuracy may have improved slightly over the first two centuries of Islam.

Keywords: Islam; qibla; Dan Gibson; early Islamic history; statistics and religion

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1. Background

Architecture is closely tied to religion, even in our modern age (De Wildt et al. 2019). For thousands of years, faithful Sunni Muslims have dutifully prayed toward the holy city of Mecca five times a day (Shia, three times a day). Ilci et al. (2018) have reported that "Facing towards the qibla ... is one of the six conditions or requisites of the prayer for being valid. In other words, if a person does not turn his/her face to the qibla direction within an acceptable declination, his/her prayer is invalid according to scholarly consensus" (p. 1642). However, could early Muslims in the first two or three centuries of Islam accurately determine the qibla? Brubaker (2019, p. 17) has mentioned the work of Dan Gibson, who claims that Mecca was not the original holy city of Islam, although Brubaker does not take a firm position on that claim. However, Petersen (1996) has stated that "Many early mosques were not built to a correct qibla orientation ... " (p. 240). King (1990) acknowledges that many early mosques did not face toward Mecca, the city (p. 246). That might imply that qiblas were not able to be measured accurately, which is an empirical rather than philosophical question, a question that can be investigated scientifically. The point of contention is not that some early mosques do not appear to point toward the city of Mecca (most scholars seem to agree on that) but on how to explain that issue, especially with respect to technological limitations at that earlier time.

As Brubaker (2019) noted, Dan Gibson (2011, 2017) has created considerable controversy over his claim that "Islam's first Holy City was Petra, not Mecca" (Lecker 2014, p. 465). Oakes (2015), after reviewing Gibson (2011), invites a response to Gibson, saying "Gibson's evidence is just begging for a response" (p. 426), echoing Waugh's (2012, p. 201) similar earlier comment that the qiblas of the earliest mosques did not seem to consistently face Mecca, an issue "which surely begs for explanation". Indeed, there have been responses to Gibson and to earlier scholars who also argued against Mecca as the first holy city. Countering such assertions are many others (Saifullah et al. 2001; King 1993). For example, Saifullah et al. (2001) argued that "A small, defiant, and largely discredited group of Orientalists have argued that the early mosques were not oriented toward Makkah . . . a theory that challenges the Muslim belief that the earliest mosques were directed toward the K'abah" (p. 1). Furthermore, Saifullah et al. (2001) argued that during the beginning of Islam "the tools for accurately determining the direction were not available at all" (p. 15). Later they claim that determining the qibla in early mosques was "as one can easily see, was only a rough guess" (p. 17). They conclude that "In the early centuries of Islam, Muslim[s] did not have tools to determine the qibla with precision" (p. 19). Similarly, Ilci et al. (2018) stated that "During the first two centuries of Islam, when mosques were being built in different geographic locations, Muslims did not have sufficient scientific background to find the direction of qibla" (p. 1643). For his part, David King (2018–2019) takes issue with Gibson's ideas, noting in various places that Gibson is an "amateur" (p. 347) and his documents "non-scholarly" (p. 347). His work is "an insult to Muslim and Western scholarship" (p. 347). King claims that Gibson's text (Gibson 2017) "is of the kind one would expect from a first-year college student" (p. 349). Rather, King argues that "Muslims for the first two centuries used folk astronomy, particularly astronomical horizon phenomena, the cardinal directions and solar risings and settings at the solstices; the reason they did this was because the Ka'ba itself is astronomically aligned and they wanted to face an edifice, the Ka'ba, not the town of Mecca" (p. 349). Furthermore, King has argued that "the earliest Muslims could never have aligned mosques accurately toward the modern direction of Petra, or, for that matter, toward the modern direction of Mecca either" (p. 351). More specifically, he argues that "the first generations of Muslims had no means whatsoever for finding the direction of Petra accurately to within a degree or two, not the least because they had no access to any geographical coordinates, let alone modern ones, and no mathematics whatsoever" (p. 354). In a different article, King (1990) argues that "In the first two centuries of Islam, when mosques were being built from Andalusia to Central Asia, the Muslims had no truly scientific means of finding the qibla" (p. 253). Anderson (2018) agrees, stating that "Hence, the only explanation for any early mosques accurately oriented toward either Petra or Mecca—if indeed any exist—is coincidence." Instead, King argues that many mosques simply faced south or in some other direction (rising summer or setting winter sun) or tried to align with the axis of the Ka'ba. King concludes that we need to "identify the diverse ways that were used for finding the qibla in each location" (p. 361) and that Gibson's ideas are "complete nonsense" (p. 363), even though "His followers will surely believe everything he writes" (p. 366). In another paper, King (2018) argues that Gibson "has no qualifications", "no understanding", "seems oblivious", "has erred monumentally", and has reached "false conclusions" (p. 9). Elsewhere, King (2018) has asserted that Gibson's "crackpot theories" are "crazy and potentially dangerous" (p. 26).

I tend to become uneasy when I observe ad hominem attacks on scholars with whom one may differ, especially when a person is labeled "discredited" without specific evidence. However, good science (and history) depends on good measurement, sound reasoning, and effective statistical methodology. It is one thing to claim something, another entirely to provide systematic and scientific/statistical evidence for that claim. As Lecker (2014, p. 467) has noted, a qibla towards Petra might also be one directed towards Jerusalem, so the ability of architects in ancient Islam to determine their direction of prayer accurately enough to distinguish between nearby target cities remains an open question (King 1986). Ordinary lay persons might question the ability of ancients to be able to determine qiblas, or the directions of prayer to holy cities accurately, as they lacked so much of the technology available to us today. As noted, King, Anderson, and presumably many other scholars would agree.

Such controversies are occurring, of course, in a contentious background in which some political interests in the West have been ideologically attacking and denigrating Muslims and Islam, possibly out of fear and their own insecurities (Sharify-Funk 2013), a process with a long history (Firestone 2019; Ismail and Mat 2016). Naturally, Muslims resent such attacks and have vigorously analyzed them and defended against them (Bazian 2018; Haddad and Harb 2014; Khan et al. 2019; Larsson 2012; Mohammed 2018). Although some may see science and statistics as a tool of the oppressor who wants to merely "display" objectivity [falsely] (Khan et al. 2019, p. 7, point number 20), I prefer to see science and statistics as a way to at least partially control for bias and to improve objectivity if done well, even though I also recognize that research can be distorted to conform to political objectives (Schumm 2015; Schumm and Crawford 2020). In other words, I agree with Sharify-Funk (2013), who recognized that "critical examination is needed" (p. 465) when dealing with emotionally charged issues. The use of statistics is one way to critically examine arguments that can be discussed in terms of specific data points.

2. Objectives

It seems to this author that Gibson deserves a better response (Oakes 2015) than ad hominem attacks. What about a scientific, statistical analysis of his claims? The main objective here is to provide the first statistical analysis of his data. Even if we do not understand exactly how the ancients might have been able to determine an accurate direction to a distant holy city, it may be possible to determine to what extent they were successful in doing so. Having some idea of their degree of accuracy would seem to be a pre-requisite to determining if they could distinguish between cities (e.g., Jerusalem versus Mecca). In this paper, I want to assess the potential accuracy of ancient Islamic qiblas. Our source of data will be limited to data provided by Gibson in his books (Gibson 2011, 2017) and his website, using his most recent data wherever possible. Gibson has provided the azimuths between different mosques or other Islamic structures and target locations, such as Mecca. He has also provided, for each mosque or structure, the degree of error in the azimuth. For example, if Mecca was distant by 45 degrees but the mosque's direction of prayer was aimed at 50 degrees, then it would require backing off 5 degrees to get to a correct azimuth (i.e., an error of −5 degrees). Lacking alternative sources of data, I will rely cautiously on data from Gibson. The primary goal is to apply statistics to determine the apparent degree of accuracy of ancient Islamic qiblas on a cautious assumption that Gibson's data were valid. However, I also wished to determine if the accuracy of qiblas was a function of an approximate distance from the target holy city or of the approximate date of construction of the buildings.

3. Methods and Procedures

3.1. Approach

The accuracy of a qibla depends on its target. Gibson's thesis is that the targets changed from Petra to a site between Petra and Mecca and then to Mecca. The anti-thesis of King and others is that Mecca was the proper site all along. First, we will test our hypotheses under Gibson's assumptions, then under King's assumption. Finally, we will attempt something of a synthesis of the competing ideas, using data which both Gibson and King might agree represented the same qibla target, what some scientists might call a "critical test" of the competing theories. Other scholars are welcome to try other approaches to comparing the theories of Gibson versus King and apply statistical testing to determine which theories better fit their data. We would prefer that to further ad hominem attacks.

3.2. Sample

For many ancient structures, neither the date of construction or the original floor plan (and hence, qibla) can be determined with precision. There are numerous mosques whose original qiblas or dates cannot be determined and, thus, were not used in our analyses (Table 1). I eliminated structures from consideration if their date of construction was not known because it hindered our assessment of our fifth hypothesis (below) or if the estimated date of construction was before 622 C.E. or after 900 C.E. (Table 1). I also eliminated structures from consideration if their qiblas did not appear to target any particular city but seemed to aim to the southeast from places in the western Mediterranean area [Gibson (2017) argues they were paralleling a line drawn from Petra to Mecca; others might think they were paralleling the long axis of the Ka'ba; Daniel Gibson (personal communication, 14 December 2019) also thinks the long axis of the Ka'ba points northwest towards Petra, where he claims the original Ka'ba was located]. Mosques for whom the best qibla was in error by more than 20 degrees were eliminated, as outliers (Table 1), from consideration. I did include Cheramin Juma (Gibson 2017) in the analyses, although on his site Gibson lists it as unknown. After eliminating ineligible structures, there were 60 left as of February 2020 (Table 2).

Table 1. Mosques not included in analyses with explanations.

Name of Mosque/Site	Date (C.E.)	Location	A	B	C	D	E	F	G
Quba Mosque	622	Medina, Saudi Arabia	X						
Prophet's Mosque	623	Medina, Saudi Arabia	X						
Mosque of the Two Qiblas	626	Medina, Saudi Arabia	X						
Janad Mosque	627	Janad, Yemen	X						
Jowatha Mosque	629	Al-Kilabiyah, Saudi Arabia	X						
Umar ibn al-Khattab Mosque	634	Dawmat al Jandal, Saudi Arabia	X						
Mosque of the Prophet Jonah	637	Mosul, Iraq	X						
Kufa Grand Mosque	638	Kufa, Iraq	X						
Ugba Ibn Nafi Mosque	640	Kairoun, Tunisia	X						
Hala Sultan Tekke	649	Larnaca, Cyprus	X						
Iman Shafi'l Mosque	649	Jeddah, Saudi Arabia	X						
Mosque of Sidi 'Ukba	686	Biskra, Algeria	X						
Dome of the Rock	690	Jerusalem	X						
Qasr Burqu'	700	Jordan desert	X						
Masjid al Khamis	717	Manama, Bahrein	X						
Mosque of Rusafa	724	Baghdad, Iraq	X						
Grand Hussein Mosque	725	Amman, Jordan	X						
Huajuexiang Mosque	742	Xian, China	X						
Amra Bathhouse	743	Jordan desert	X						
Shibam Palace	753	Shibam, Yemen	X						
Masjid al Jami Grand Mosque	772	Ishfan, Iran	X						
Qasr Uweinid	8th C.	Jordan desert	X						
Erbil Grand Mosque	8th C.	Erbil, Iraq	X						
Be'er Ora Qiblatain Mosque	8th C.	Be'er Ora, Israel	X						
Fenghuang Mosque	8th C.	Hangzhou, China	X						
Job's Tomb Shrine	8th C.	Salalah, Oman	X						
Al-Asha'ir Mosque	820	Zabid, Yemen	X						
Grand Mosque of Shibam	871	Shibam, Yemen	X						
Sidi Ghanem Mosque	678	Mila, Algeria		X					
Graveyard of Sidi Ukba	686	Biskra, Algeria		X					
Jami' al-Zaytuna	732	Tunis, Tunisia		X					

Table 1. *Cont.*

Name of Mosque/Site	Date (C.E.)	Location	A	B	C	D	E	F	G
Ribat Fortress	770	Ribat, Tunisia		X					
Tauste Graveyard	772	Zaragoza, Spain		X					
Cordoba Mosque	784	Cordoba, Spain		X					
Shrine of Kazmiyya	799	Baghdad, Iraq		X					
Dougga Mosque	800	Dougga, Tunisia		X					
Rand Mosque of Kairoun	817	Kairoun, Tunisia		X					
Moulay Idriss, II Tomb and Mosque	828	Fex, Morocco		X					
Jami Uqba ibn Nafi	836	Kairoun, Tunisia		X					
Great Mosque of Susa	c. 850	Susa, Tunisia		X					
Small mosque with graveyard	c. 850	Houmt Souk, Tunisia		X					
Great Mosque of Sfax	850	Sfax, Morocco		X					
University of al-Qarawiyyin	859	Fez, Morocco		X					
Mosque with Three Doors	866	Kairoun, Tunisia		X					
Grand Mosque of Mahdia	916	Mahdia, Tunisia		X			X		
Medjez el-Bab	944	Beja, Tunisia		X			X		
Grand Mosque of Sale	1028	Sale, Morocco		X			X		
Grand Mosque of Tangier	1196	Tangier, Morocco		X			X		
Al-Muwaqqar graveyard	723	Muwaqqar, Jordan			X				
Qasr el-Bai'j	410	Jordan desert				X			
Harat Great Mosque	1200	Harat, Afghanistan					X		
Abdul Qader Yagouri Mosque	c. 750	Bini Abbas, Algeria						X	X
Qasr Hallabat	827	Jordan desert							X
Masjid I Jami, Mosque of Fahraj	c. 850	Fahraj, Iran							X

Code: A = Original foundation/qibla could not be determined; B = Qibla appears to roughly parallel the line from Petra to Mecca or the line of the long axis of the Ka'ba; C = Azimuth information missing; D = Date of construction before 622 C.E.; E = Date of construction after 900 C.E.; F = Reported data probably incorrect; G = Most likely qibla direction in error by more than 20 degrees.

Table 2. Mosque/Site data used in analyses (N = 60).

NAME of MOSQUE	DATE (CE)	Location	Original Azimuth	Error Petra	Error Mecca	Error Jerusalem	Error Between
Cheraman Juma	629	Methala, Kerala State, India	304.3 Petra (J)	0.26	75.01	1.65	37.64
Hama Great Mosque	637	Hama, Syria	193.87 Petra	0.61	25.81	−7.17	13.21 12.3
Amr ibn Al-as	642	Fustat, Egypt	90.00 Petra	6.10	−46.00	28.30	19.95 −29.4
Aqaba Umayyad Mosque	~650	Aqaba, Jordan	36.24 Petra	10.80	−114.40	31.20	51.80 −113.0
Kathisma Church	~650	Bethlehem, Israel	174.00 Petra	1.90	16.90	147.70	9.30 8.5
Seven Sleepers Mosque	~650	Amman, Jordan	196.03 Petra	−0.30	35.10	−63.30	17.40 21.9
Jerash Umayyad Mosque	~650	Jerash, Jordan Also Abu Dulaf mosque	196.32 Petra	5.02	35.20	−31.80	20.10 22.6

Table 2. *Cont.*

NAME of MOSQUE	DATE (CE)	Location	Original Azimuth	Error Petra	Error Mecca	Error Jerusalem	Error Between
Qasr Mushash Mosque	~650	Desert Castle, Jordan	202.95 Petra	−4.10	40.60	−65.10	18.25 25.1
Zeila Qiblatain (Left)	~650	Zeila, Somalia	339.10 Petra (J)	−0.60	−2.20	−1.80	0.80 0.50
Dome of the Chain	690	Jerusalem	172.03 Petra	−1.00	14.70	−94.50	6.85 6.2
Qasr Humeima	699	Humeima, Jordan	20.64 Petra	8.50	−133.02	23.58	−82.9 −138.2
San'a Grand Mosque	705	San'a, Yemen	333.60 Petra	0.36	7.40	−1.47	3.52 3.3
Khirbat al Minya	706	Khirbat al Minya, Israel	182.67 Petra	0.80	22.14	−10.58	11.47 11.5
Hajjaj Mosque	706	Wasit, Iraq	234.98 P/M	−26.5	25.3	−35.4	0.60 −7.4
Masjid al-Tarik Khana	708	Damghan, Iran	244.82 249.56 P/M (P)	10.30 −5.6	20.20 25.0	15.20 −10.5	4.95/10.9 5.0
Al-Aqsa Mosque	709	Jerusalem	169.61 Petra	−3.43	12.31	−179.8	4.44 3.70
Al-Umawi al-Kabir, Damascus Umayyad Mosque	709	Damascus, Syria	177.21 P/M	−20.25 −16.0	8.33 12.5	−30.53	1.75 −1.1
Amman Umayyad Mosque	710	Amman, Jordan	181.50 P/M	−13.2	20.7	−72.1	7.7
Qasr al-Kharana	710	Desert Castle, Jordan	175.01 P/M	32.30 −37.30	12.10	−98.00	12.60 −4.4 or 3.01?
Khann al-Zabib	712	Qatrana, Jordan	171.93 P/M	−33.80	11.10	−118.10	−11.35 −3.2
Um Walid Mosque	712	Al Zafaran, Jordan	197.41 Petra	1.20	37.50	−89.50	19.35 24.9
Khirbat al-Mafjar	714	Jericho, Israel	180.03 Petra	−0.59	21.51	−61.34	10.46 11.5
Anjar Palace Mosque	714	Anjar, Lebanon	190.76 Petra	3.61	27.36	−6.17	15.49 15.3
Aleppo Umayyad Mosque	715	Aleppo, Syria	178.70 P/M	−15.50	8.40	−21.70	3.55 −5.00
Qasr Qastal	720	Qastal, Jordan	191.74 Petra	−5.20	31.20	−81.50	13.00 18.2
Mosque of 'Umar	721	Bosra, Syria	183.63 P/M	−18.74	19.45	−51.60	0.36 3.9
Qasr Muwaqqar	723	Muwaqqar, Jordan	182.98 P/M	−18.20	21.60	−84.60	1.70 7.5

Table 2. *Cont.*

NAME of MOSQUE	DATE (CE)	Location	Original Azimuth	Error Petra	Error Mecca	Error Jerusalem	Error Between
Qasr al-Hayr al Gharbi	726	Hayr al Gharbi, Syria	191.01 P/M	−13.86	20.27	−27.10	3.21 3.3
Banbhore Mosque	727	Banbhore, Pakistan	265.78 Mecca	−22.61	−2.44	−25.55	12.53 −16.2
Qasr Hayr al Sharqi	728	Hayr al Sharqi, Syria	192.61 P/M	−21.2	15.6	−32.6	2.80 −3.7
Umayyad Palace	730	Amman Citadel, Jordan	159.46 Mecca	−35.25	−1.36	−94.10	18.30 −14.3
Ba'albeck Mosque	740	Ba'albeck, Lebanon	176.86 P/M	−13.36	12.02	−23.48	0.67 −0.80
Qasr Bayir	743	Desert Castle, Jordan	166.67 Mecca	−81.60	4.20	−143.20	38.70 −15.8
Mushatta Palace	743	Desert Castle, Jordan	195.13 Petra	−4.10	34.32	−78.52	15.10 20.8
Qasr Tubah	743	Desert Castle, Jordan	292.02 Jerusalem	67.40	129.20	0.00	98.30 111.3
Harran Mosque and University	744	Harran, Turkey	191.74 P/M	−13.87	14.52	−20.97	0.33 −1.5
Um Jimal Umayyad Mosque	749	Um el-Jimal, Jordan	180.00 P/M	−21.90	16.60	−60.50	2.65 1.4
Um Jimal Later Castellum Mosque	749	Um Jimal, Jordan	203.03 Petra	1.10	39.60	−37.60	24.5
Kufa Grand Mosque (rebuilt)	749	Kufa, Iraq	195 Mecca	−65.0	−6.0	−75.0	−29
Qasr Aseikhin	~750	Desert Castle, Jordan	163.89 Mecca	−55.20	−1.70	−100.00	−28.45 −20.9
Qasr Al-Fudayn	~750	Mufraq, Jordan	178.19 P/M	−19.90	15.50	−57.30	2.20 1.3
Qasr ain as-Sil	~750	Azrak, Jordan	180.30 P/M	−37.60	15.30	−85.30	11.15 −3.4
Azraq Fort Mosque	~750	Azraq, Jordan	184.81 P/M	−33.00	19.90	−81.30	6.55 1.3
Um Jimal Later Castellum Umayyad Mosque	~749	Um Jimal, Jordan	203.03 Petra	1.10	39.60	−37.60	20.21 24.5
Bazaar Qaisaqiya	~750	Erbil, Iraq	218.53 P/M	−14.60	23.50	−22.80	4.45 0.9

Table 2. *Cont.*

NAME of MOSQUE	DATE (CE)	Location	Original Azimuth	Error Petra	Error Mecca	Error Jerusalem	Error Between
Al-Sawaf Mosque Grounds	~750	Erbil, Iraq	234.35 Petra	1.20	39.40	−7.00	20.30 16.8
Yamama Great Mosque	~750	Yamama, Saudi Arabia	280.45 P/M	−22.30	30.70	−27.60	4.20 −9.3
Qiblatain Mosque of Oman	~750	Ibra, Oman	294.00 Petra	−1.20	24.60	−4.80	11.70 6.6
Huaisheng Mosque	~750	Guangzhou, China	291.66 P/M	−3.30	7.10	−4.90	1.90 0.1
Bibi Samarkan	~750	Samarkan, Uzbekistan	261.64 Petra (J)	1.78	21.86	−1.23	11.82 8.5
Sahi Ramdah Mosque	~750	Bowshar, Oman	292.79 Petra	−0.58	26.19	−4.24	12.81 7.5
Mosque of Mansur	762	Baghdad, Iraq	200.03 Mecca	−51.10	0.00	−61.30	25.94 −30.5
Qasr Ukhaydir	764	Kufa, Iraq	198.24 Mecca	−61.61 −57.1	3.90 0.4	72.35 −68.7	32.75 −33.5
Raqqa Mosque	772	Raqqa, Syria	193.90 P/M	−15.17	16.89	−24.12	0.86 −0.6
Qasr al-Hallabat Mosque	827	Desert Castle, Jordan	163.55 Mecca	−40.00	0.70	−88.00	19.65 −14.5
Great Mosque of Samarra	847	Samarra, Iraq	197.79 Mecca	−46.01	1.13	−56.10	22.44 −26.5
Nine Domed Mosque	~850	Balkh Province, Afghanistan	241.23 Mecca	−24.20	−3.20	−27.40	−13.70 −17.3
Ansaq Friday Mosque	~850	Ansaq, Iraq	207.11 Mecca	−27.82	4.15	−33.77	−11.83 −15.7
Al Balid Mosque	~850	Salalah, Oman (old Zafar)	285.05 Mecca	−26.34	−5.33	−29.2	−15.83 −20.2
Abu Dalaf Mosque	859	Samarra, Iraq	191.57 Mecca	−51.02	−4.60	−61.02	−27.81 −31.8
Ibn Tulun Mosque	876	Cairo, Egypt	145.40 Mecca	61.21	9.27 9.3	83.51	35.24 25.8

Petra = qibla appears to point towards Petra; Mecca = qibla appears to point towards Mecca; Jerusalem = qibla appears to point towards Jerusalem; P/M = qibla appears to be a location between Petra and Mecca. A secondary letter such as (J), (B), or (P) indicates that a second city might be close to the same qibla direction as the first city mentioned. Where two sets of numbers are provided, this indicates that Gibson seems to have changed the values, the most recent being the added ones, usually from his website rather than his books. We used the more recent numbers for our statistical analyses, on the presumption they would be more likely to be correct.

3.3. Analysis

When random, as opposed to systematic, error is involved, measurements of target variables tend towards normal distributions, centered on a sample mean score. In the case of qiblas, the mean score should be near zero, with a nearly even division of lower (negative) or higher (positive) angles, as can be assessed by a one sample *t*-test or a chi-square test with one degree of freedom. Whether a distribution is normal or approximately normal can be determined by inspection of its histogram or by a Kolmogorov-Smirnov one-sample test. A one sample t-test can be used to determine if the mean score differs significantly from zero, where zero would represent an entirely accurate qibla direction. As a practical method of assessing accuracy, I wanted to determine what percentage of mosques or other structures would have qiblas with an accuracy of ±2, 3, or 5 degrees. Using such a tight requirement was risky; Ilci et al. (2018) found that mosques built between 1300 and 1660 in part of northern Turkey had qibla errors from 6 to 18 degrees. SPSS version 26 was used for all statistical calculations.

4. Hypotheses

1. The average direction of prayer. The null hypothesis is that the average direction of prayer will be centered on zero, as assessed by a one sample *t*-test and a chi-square test with one degree of freedom. If the null hypothesis is rejected, that might suggest a greater inaccuracy in qibla determination, with some type of systematic, rather than merely random, bias.
2. The distribution of qiblas around their mean will be normally distributed by inspection and/or a test for non-normality, specifically a Kolmogorov-Smirnov one sample test of normality.
3. The limits of 2, 3, and 5 degrees, plus or minus, were considered. My thinking was that if qiblas could be determined at those levels of accuracy, then ancient architects could probably distinguish between adjacent cities as long as those cities were several degrees apart in terms of their azimuths; otherwise, azimuths might not be distinguishable.
4. Qibla accuracy and distance from holy city. The null hypothesis was that there would be no association between the qibla accuracy and distance from the holy city, tested with a Pearson zero-order correlation coefficient and a nonparametric Spearman rho correlation coefficient. I did not have a prediction here of the outcome.
5. Qibla accuracy and approximate date of construction. The null hypothesis was that there would be no association between the qibla accuracy and the approximate time of construction of the buildings, tested with a Pearson zero-order correlation coefficient and a Spearman rho correlation coefficient. I was not sure if the qibla accuracy would improve or decline over time. I also planned to correlate the date of construction with the distance from the target city, which was expected to be positive on average.

5. Results

5.1. Under Gibson's Assumptions

Here we assume that the qibla changed from Petra to Mecca, generally in accordance with Gibson's claims.

1st Hypothesis, Direction of Prayer. The mean score for the 60 qiblas was 0.156 of a degree error, with a standard deviation of 4.07 degrees of error and a standard error of 0.526 degrees of error. The median was 0.050 of a degree of error. Using bootstrap methods with 1000 samples, 95% confidence intervals of −0.87 to 1.22 degrees of error for the mean, −0.80 to 0.90 degrees of error for the median, and 3.27 to 4.76 degrees of error for the standard deviation were obtained. The one sample *t*-test value was 0.297 for 59 degrees of freedom, $p = 0.768$. The one sample chi-square value for one degree of freedom, to check whether there were equal numbers of errors on either side of zero, was 0.000, $p = 1.00$. Using a one sample Wilcoxin Signed Rank Test to compare the actual data to a median of zero yielded non-significant results ($p = 0.908$). All three tests results indicated that the average qibla error was very close to zero, with an even number of errors on either side of zero.

2nd Hypothesis, Normal Distribution. While the Kolmogorov-Smirnov one-sample test yielded a significant result ($p = 0.013$), an inspection of Figure 1 suggests that the actual distribution was mound-shaped and approximately normally distributed, except that a higher than expected number of scores occurred near the zero qibla error, reflecting a higher degree of kurtosis. By contrast, the same K-S test against a uniform distribution yielded a far more significant result ($p < 0.005$), rejecting the null hypothesis that the distribution was of a uniform shape. In other words, the violation of normality was likely due to a greater than expected accuracy rather than higher rates of inaccuracy, which would have favored more of a uniform distribution.

3rd Hypothesis, Percentages of Accuracy. Over half (51.7%) of the qiblas were within plus or minus two degrees of accuracy; 61.7% were within three degrees of accuracy; and 81.7% were within five degrees of accuracy. Over a quarter of the qiblas (26.7%) were within one degree of accuracy. While some qiblas were more accurate than others, such results do not seem to fit the premise that early Muslim architects were incapable of determining reasonably accurate qiblas.

4th Hypothesis, Qibla Accuracy and Distance. The zero-order correlation between the distance from the target city and the error of the qibla was $r = -0.116$ ($p = 0.376$). The results for the nonparametric Spearman rho were similar, *rho* = −0.125 ($p = 0.340$). There was a non-significant trend for the qibla error to be lower (i.e., greater accuracy) with greater distances; perhaps, greater care was taken for mosques built farther from their direction of prayer.

5th Hypothesis, Qibla Accuracy and Date of Construction. The zero-order correlation between the date of construction and qibla error was $r = -0.123$ ($p = 0.348$), as was the Spearman rho (−0.126, $p = 0.339$). There was a non-significant trend for the qibla accuracy (i.e., lower error) to improve over historical time. The distance and date were correlated positively with $r = 0.258$ ($p < 0.05$), although the Spearman rho was much larger, 0.456 ($p < 0.001$), which may reflect the expansion of Islamic influence over historical time.

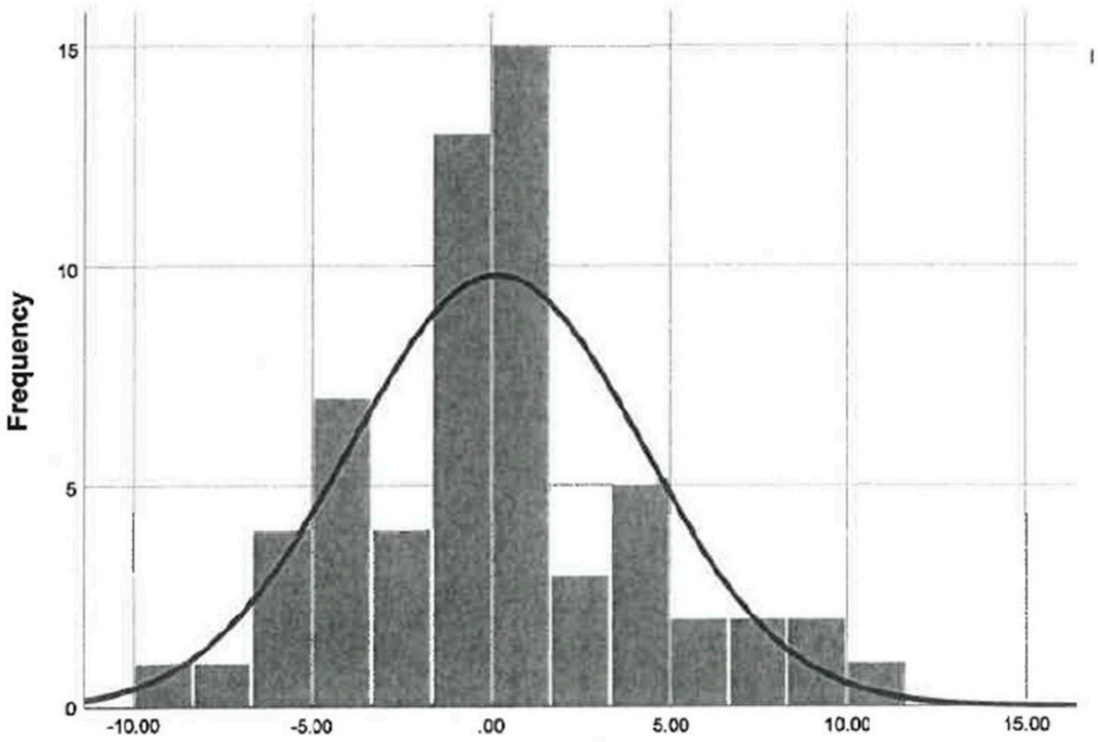

Figure 1. Histogram with normal curve overlay for the degrees of error in early Islamic qiblas.

5.2. Under King's Assumptions

Here we assume that the qibla did not change and was always Mecca from 632 C. E. onward. We did not try to test the hypothesis that the qibla began toward Jerusalem and then was changed, before Muhammad's death (c. 632 C.E.), to Mecca (Saifullah et al. 2001).

1st Hypothesis, Direction of Prayer. The mean score for the 60 qiblas was 13.03 of a degree error, with a standard deviation of 33.93 degrees of error and a standard error of 4.38 degrees of error. The median was 15.55 degrees of error. Using bootstrap methods with 1000 samples, 95% confidence intervals were obtained of 4.05 to 21.11 degrees of error for the mean, 12.02 to 20.70 degrees of error for the median, and 16.68 to 47.25 degrees of error for the standard deviation. The one sample *t*-test value was 2.97 for 59 degrees of freedom, $p = 0.004$. The one sample chi-square value for one degree of freedom, to check whether there were equal numbers of errors on either side of zero, was 21.60, $p < 0.001$. Using a one sample Wilcoxin Signed Rank Test to compare the actual data to a median of zero yielded significant results ($p < 0.001$). All three test results indicated that the average qibla error was significantly different from zero under the King assumption.

2nd Hypothesis, Normal Distribution. While the Kolmogorov-Smirnov one-sample test yielded a significant result ($p = 0.001$), the inspected results were similar to those in Figure 1 inasmuch as the actual distribution was mound-shaped and approximately normally distributed, except that a higher than expected number of scores occurred near the zero qibla error, reflecting a higher degree of kurtosis; however, there were also larger outliers than those found in Figure 1. By contrast, the same K-S test against a uniform distribution yielded equally significant results ($p < 0.001$), rejecting the null hypothesis that the distribution was of a uniform shape. In other words, the violation of normality was likely due to a greater than expected accuracy for a few mosques but also to rather large outliers at both extremes of the distribution.

3rd Hypothesis, Percentages of Accuracy. Few (10.0%) of the qiblas were within plus or minus two degrees of accuracy; 13.3% were within three degrees of accuracy; 20.0% were within five degrees of accuracy. Only 5% of the qiblas were within one degree of accuracy. Only when larger ranges of degrees of accuracy were considered, did the percentages increase (±20 degrees, 55.0%; ±30 degrees, 76.7%; ±40 degrees, 90.0%; ±50 degrees, 93.3%; and ±100 degrees, 95.0%). Thus, aside from Gibson's contrary thesis, it would indeed appear that King and his supporters were correct in that the qiblas towards Mecca would not have appeared to have been very accurate.

4th Hypothesis, Qibla Accuracy and Distance. The zero-order correlation between the distance from the target city and the error of the qibla was $r = -0.042$ ($p = 0.748$). The results for the nonparametric Spearman rho were far stronger, $rho = -0.404$ ($p = 0.001$). Overall, the results were mixed.

5th Hypothesis, Qibla Accuracy and Date of Construction. The zero-order correlation between the date of construction and qibla error was $r = -0.019$ ($p = 0.885$), while the Spearman rho was −0.245 ($p = 0.059$). While the results were mixed, there seemed to be a non-significant trend for the qibla accuracy to improve over historical time. The distance and date were correlated similarly to before, since the same data and variables were being used.

6. Attempting a Synthesis with Independent Data

Thus far, we have a dilemma. From Gibson's perspective, qiblas appear to be reasonably accurate. From King's perspective, qiblas do not appear to be very accurate, which agrees with his (King's) position. That is to say that the data would support both Gibson and King, if we accept their initial assumptions. A good scholar will look for disconfirming evidence of his or her pet ideas in order to avoid being a victim of confirmation bias (Schumm 2015), a bias whereby scholars tend to focus on results that fit their preconceived notions. Two possibilities emerged for testing qibla accuracy in a way that might synthesize the results of the competing assumptions.

Avni Data. First, I came across a report by Avni (1994) that listed qiblas of a dozen mosques in the Negev, near the border of Egypt. The qibla azimuths ranged between 158 and 182 degrees, with a mean of 167.75 and a standard deviation of 5.85. Coins and artifacts dated these sites to the middle of the seventh century, and probably no earlier than 700 CE. The azimuths clearly do not point toward Petra, which is to the east southeast, but they do generally point toward Mecca, though often missing it to the west, aiming closer to due south than the more correct south southeast direction (However, only a couple were aimed within 5 degrees of due south). One might have hoped that this data would have served as an excellent test of the two theories, but Gibson himself reports that some mosques had Meccan qiblas by the early to mid-700s. Some of the mosques in Avni (1994) appear from his photos to be little more than a single layer of rocks on open ground, and it stretches credulity to think such structures would have remained completely undisturbed for over 1300 years or that their qiblas would have been sighted by highly trained Islamic architects. The standard deviation of the azimuths is a bit larger than that of our findings, which may reflect positioning by Muslims with lower levels of training in qibla positioning. The two standard deviations can be compared statistically using an F-test with 11.59 degrees of freedom for which the critical value (alpha = 0.05) was 1.96. The actual F value was 2.07 ($p < 0.038$), which indicates that the two standard deviations are significantly different, as might be expected if architects of large mosques were more highly trained than those who built lesser structures in more remote areas. Thus, it seems that more accurate qiblas were obtained by architects who were working on larger structures compared to those who built far smaller structures in more remote areas. However, though the data here are limited, they suggest that early mosques aimed towards Mecca were relatively accurate, supporting Gibson's thesis.

Gibson data. Second, in response to questions raised by a reviewer of this report, I narrowed down the number of mosques under consideration. Gibson, among the 60 mosques in this study, featured 14 mosques or other structures that he (Gibson) agreed faced Mecca. Presumably, King would also agree that they faced Mecca. Given contrarian positions on qibla development over the early Islamic centuries, here we have a potential area of agreement that might allow for a critical test and for a synthesis of the competing theories. If these mosques had relatively accurate qiblas, then it would appear that it was possible that most of the mosques did—suggesting the Gibson was more correct; if these mosques did not have accurate qiblas, then it would appear that perhaps few of the mosques had accurate qiblas—and King would be more correct. For these 14 mosques, the mean, median, standard deviation, and standard error were −0.341, −0.680, 4.184, and 1.118, respectively. Using bootstrap methods with 1000 samples, 95% confidence intervals were obtained of −2.46 to 1.76 degrees of error for the mean, −3.20 to 1.13 degrees of error for the median, and 2.33 to 5.50 degrees of error for the standard deviation. The one sample t-test value was −0.305 for 13 degrees of freedom, $p = 0.765$. The one sample chi-square value for one degree of freedom, to check whether there were equal numbers of errors on either side of zero, was 0.286, $p = 0.593$. Using a one sample Wilcoxin Signed Rank Test to compare the actual data to a median of zero yielded significant results ($p = 0.507$). Although the non-significant results may reflect the small sample size and low statistical power, neither of the Kolmogorov-Smirnov tests for normal or uniform distributions were significant. 42.9% of the qiblas were within plus or minus two degrees of error; 50.0% were within three degrees of error, with 78.6% and 100.0% being within five and ten degrees of error, respectively. 21.4% were within ± one degree of error. None of the correlations among qibla error, distance, or date were statistically significant in this small sample of mosques. Despite the small sample, among the 14 mosques, qibla accuracy was fairly good, with non-significant differences from normal distributions and with central tendencies bracketing zero. The results of our two follow-up analyses, limited to the accuracy of mosques presumably facing towards Mecca, found that accuracy was relatively good, in support of Gibson's thesis and contrary to King's antithesis.

7. Further Critical Testing

A counter argument could be made against the Gibson hypothesis. Perhaps it should be no surprise that Meccan qiblas were accurate, but perhaps other qiblas were not, if limited to the same range of years as the Meccan-oriented mosques. Therefore, our data were limited to non-Meccan qiblas after the year 726 C.E. to test this alternative explanation. Eighteen mosque qiblas were analyzed. For these 18 mosques, the mean, median, standard deviation, and standard error were −0.894, −0.290, 2.778, and 0.655, respectively. Using bootstrap methods with 1000 samples, 95% confidence intervals were obtained of −2.25 to 0.262 degrees of error for the mean, −1.500 to 1.199 degrees of error for the median, and 1.385 to 3.996 degrees of error for the standard deviation. The one sample t-test value was -1.366 for 17 degrees of freedom, $p = 0.190$. The one sample chi-square value for one degree of freedom, to check whether there were equal numbers of errors on either side of zero, was 0.222, $p = 0.637$. Using a one sample Wilcoxin Signed Rank Test to compare the actual data to a median of zero yielded significant results ($p = 0.507$, remarkably the same p level as for the 14 mosques). Although the non-significant results may reflect the small sample size and low statistical power, the

Kolmogorov-Smirnov test for a normal distribution was not significant ($p = 0.080$), while the test against a uniform distribution was significant ($p < 0.001$). 77.8% of the qiblas were within plus or minus two (and three) degrees of error, with 94.4% and 100.0% being within five and ten degrees of error, respectively. 33.3% were within ± one degree of error. None of the correlations among qibla error, distance, or date were statistically significant in this small sample of mosques, except for the Spearman nonparametric correlation between the date and distance, *rho* = 541, $p = 0.020$. Comparing the qibla error scores for the 14 Meccan-oriented mosques and the 18 other-oriented mosques yielded non-significant results across the two groups, with $t(30) = -0.449$ (p = 0.657, two-tailed, Cohen's d = 0.16, less than a "small" effect size per Cohen, 1992) and a Mann-Whitney *U* test = 118.50 ($p = 0.779$, two-tailed exact). The standard deviations of the two groups were not significantly different either, $F(13, 17) = 2.27$ ($p < 0.058$). Thus, there did not appear to be statistically significant differences in the means or standard deviations as a function of the different apparent qibla directions. In other words, the qibla accuracy did not vary significantly as a function of Meccan or non-Meccan orientations.

8. Discussion

On average, under Gibson's assumptions, the mosque qiblas appeared to be accurate a majority of the time, within two degrees of azimuth, and nearly always within ten degrees, better than had been expected. Cohen (1992) set a standard in social science that half a standard deviation was an effect large enough to detect with the naked eye, which, in this case, would be about two degrees of azimuth, roughly the width of a human finger extended at arm's length. The results were balanced with no significant differences in the number of errors on either side of zero. The results for the qibla error were approximately normal in appearance, except that a higher percentage of results were closer to zero than would have been expected for a normal distribution. Although the results were significant in terms of rejecting the hypothesis that the results were exactly normal, that result combined with a higher percentage of near misses than would be expected under normal conditions probably strengthens our results, rather than detracting from them. Greater distances did not seem to lead to greater qibla errors. As might be expected with the expansion of Islamic influence in the first two centuries after Muhammad, a strong association was found between more recently constructed mosques and further distances. Qibla accuracy seemed to increase for more recently built mosques, a finding that merits further research to determine if technology had improved or if a greater certainty about qibla directions had a positive effect on accuracy.

Under King's assumptions, many of the mosques did not appear to have accurate qiblas, in agreement with King's assertions. His observations are correct, given his assumption; yet, when agreement between King and Gibson might be expected—for mosques aimed towards Mecca—the results suggested fairly high levels of qibla accuracy. That is, when we limited the analyses to mosques that all would probably agree *were* oriented towards Mecca, *high* levels of qibla accuracy were obtained, suggesting that accuracy might have been possible for qiblas facing different sites other than Mecca itself. When the latter hypothesis was tested for the other 18 mosques built about the same time as the 14 Meccan-oriented mosques, no significant differences were found in the qibla accuracy; other parameters of general qibla accuracy were similar across both groups.

9. Limitations

The results here are limited by their reliance upon data provided by Dan Gibson. As he continues to add new sites to his website, any given analysis of data on an earlier date may become outdated, even though our data reflected his website's content as of early February 2020. Our discussion has not attempted to explain how ancient Islamic architects determined directions from one location to another. I did not find any evidence that Gibson was making up his results apart from actual geographic measurements or real data, as have some recent scholars (Schumm et al. 2019a, 2019b). I have had email discussions with Mr. Gibson in an attempt to clarify some discrepancies found between the data reported in his books and that reported on his website. If my statistics are in error, I hope that others, including Dr. King, who admits to his own "distinct penchant with respect to statistics" (King 2018, p. 18), will correct us, especially if "statistics are on my [his] side this time" (p. 18).

10. Implications

If one were to try to determine which of two adjacent cities were targets if the angle between them was smaller than two degrees, I think it would be a challenge to distinguish between them, as the difference would be only about one half a standard deviation, although it might have to be done in conjunction with other available information (e.g., date of construction) or associated historical events. If the angles were different by more than four degrees, making distinctions would be more certain because that difference would represent about one standard deviation or more. For example, suppose the true qibla to Mecca was 160 degrees but the mosque was aimed due south (180 degrees). Our results would suggest that it was more likely, from a statistical perspective, that the architects intended the qibla to be due south, for whatever reason, rather than aimed to face Mecca. If, on the other hand, the mosque was aimed at 158 degrees, that would probably mean the intended qibla was either Mecca or an attempt to parallel the long axis of the Ka'ba, despite the small error. If the error was more than four to eight degrees, the alignment may have been set up by mistake or based, at least partly, on some other criterion. However, if the objective is to compare *groups* of qiblas, then the standard error becomes more relevant and differences of as little as one or two degrees might represent a statistically significant difference.

11. Conclusions

In spite of the limitations of this study, the results found here appear to indicate that qiblas could be determined with a fair degree of accuracy in the first two or three centuries of Islam, regardless of the apparent sites faced by the mosques. At the same time, King's observations that, assuming Mecca to be the only qibla, qiblas could not be determined with much accuracy, are factually correct if one accepts his assumption. However, we found that, when assessing only mosques regarding which both sides would agree should have qiblas towards Mecca, qiblas were relatively accurate, though not perfect. We also found that qiblas in other directions than Mecca had similar degrees of accuracy as those known to have been towards Mecca at about the same historical time. Thus, overall, it appears that most mosques in the first two centuries of Islam could have had a fairly high degree of qibla accuracy, maybe even higher than mosques in far more recent centuries (Ilci et al. 2018). *How* early Islamic architects were able to obtain high rates of qibla accuracy remains to be determined but also remains an interesting question. Now, knowing that they did have high rates of accuracy, this has surely become a reasonable question for further inquiry. Furthermore, a related question would be explaining how some Islamic architects were able to achieve qibla accuracies of plus or minus one or two degrees, while others erred by ten or more degrees. Were these different architects using different methods for determining the qibla direction? If so, how or why were their methods different? Were the architects using the same method but some with fewer mistakes, or were the architects using very different methods, with some methods being more accurate than others?

Funding: No funding from any source was used to support this research.

Acknowledgments: My appreciation is expressed to Dan Gibson and Zvi Goldman for their helpful comments on earlier drafts of this manuscript, as well as to two anonymous reviewers who encouraged a deeper analysis of the data. Dan Gibson deserves even more appreciation for making his data publicly available for independent study and analysis and for his personal courage in tackling potentially sensitive research issues.

Conflicts of Interest: The author declares no conflict of interest. The author is a substitute pastor at a non-denominational Christian church, Ashland Community Church, south of Manhattan, Kansas, USA.

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