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Contents / Contenido

Ancient Pututus Contextualized
Integrative Archaeoacoustics at Chavín de Huántar, Peru

Miriam A. Kolar, with
John W. Rick, Perry R. Cook, and Jonathan S. Abel

This study of ancient sound-producing instruments within a comprehensive archaeoacoustic investigation is greatly enhanced by an integrative methodology that explores interrelationships among instrumental and environmental acoustic dynamics, and considers their auditory perceptual implications. The 3000-year-old Andean Formative Period ceremonial center at Chavín de Huántar presents both *Strombus galeatus* marine shell horns known as *pututus* and well-preserved architecture, whose acoustics can be tested, measured, and computationally modeled. Comparative acoustic measurements of site instruments and architecture, further informed by on-site psychoacoustic experimentation, provide information about the auditory environment experienced by ritual participants in ancient Chavín. We present findings that demonstrate an architectural acoustic mechanism specifically linking the Chavín *pututus* to the area of the Lanzón Gallery and Circular Plaza, focal in this reputed oracle center. We propose a sounding oracle, and how it could be given voice.

El presente estudio sobre instrumentos sonoros antiguos, llevado a cabo en el marco de una investigación arqueoacústica comprensiva, se beneficia de una metodología íntegra que explora las interrelaciones entre las dinámicas acústicas instrumentales y ambientales y sus implicaciones auditivas. El centro ceremonial de Chavín de Huántar, Perú, un sitio arqueológico del Periodo Formativo, con una antigüedad de aproximadamente 3000 años, presenta tanto cuernos de caracoles marinos, *Strombus galeatus*, denominadas *pututus*, como también una arquitectura bien preservada, dos hechos que permiten realizar pruebas y mediciones y desarrollar modelos computacionales. Medidas acústicas comparativas, completadas por la experimentación psicoacústica, proveen datos sobre el ambiente auditivo experimentado por quienes participaban en los rituales del antiguo Chavín. Nuestros resultados demuestran un mecanismo acústico-arquitectónico que relaciona los *pututus* de Chavín con el área de la Galería del Lanzón y la Plaza Circular, punto neurálgico de este centro considerado como un sitio de oráculo. Planteamos la idea que se trataba de un oráculo sonoro, y mostramos cómo éste posiblemente llegó a tener voz.

A Ceremonial Complex Tuned to the Senses

The site at Chavín is known as a ceremonial complex, and indeed its monumental architecture and material record substantiate this idea (Moore 1996; Kembel and Rick 2004). Historical texts from the 17th century identify Chavín as a temple and oracle site (Lumbreras 2007): its 4.5 m-high relief-carved granite monolith[1] known as the "Lanzón" (a Spanish-language reference to its spear-like form) or "the Great Image" (Rowe 1962: 8-9), is considered the likely phys-

1 The Lanzón has also been also referred to as "Wira Kocha" (Tello 1906: 175), "the Wari" (Diessl 2004: 500), which in regional Quechua also signifies "hidden; animal cave" (Parker and Chávez 1976), or by some present-day locals, "la Wahnka," a Quechua moniker that refers to its standing "long rock/boulder" form (Parker and Chávez 1976; Anonymous 2008).

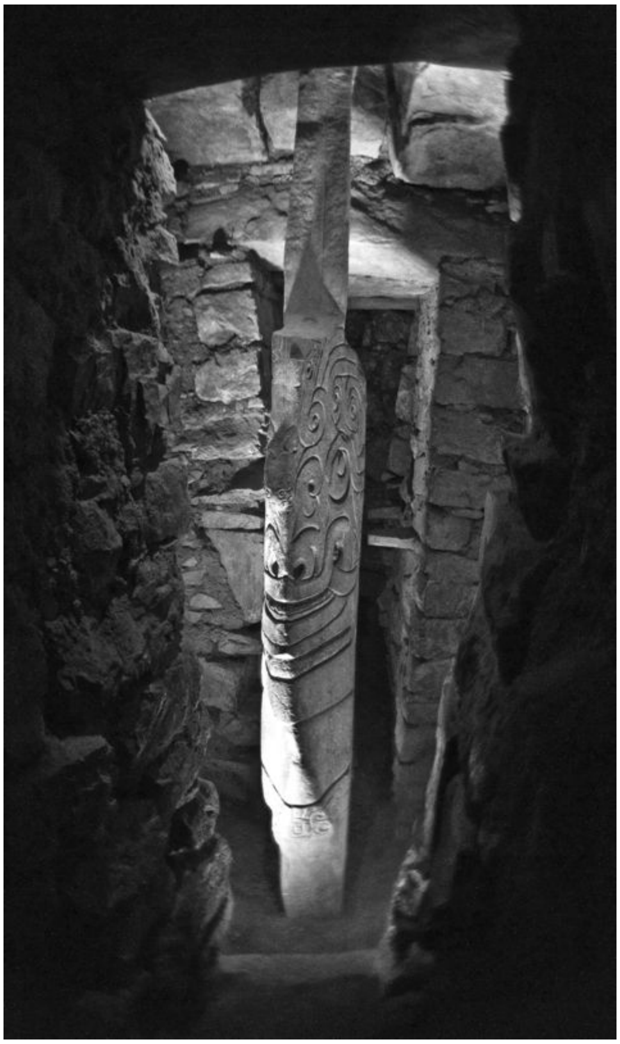

Fig. 1 The "Lanzón"/"Great Image" of Chavín: relief-carved granite monolith, approx. 4.5 m high, within its extant cruciform room in the Lanzón Gallery. Photo by José Luis Cruzado Coronel.

ical representation or manifestation of this oracle (Paulsen 1974), and the site's principal deity (Fig.1). Chavín's massive stone and mortar architecture, a product of as much as 700 years of active development (1200-500 BC), is composed of high buildings surrounded by multilevel terraces and sunken plazas with flanking staircases (Fig. 2). Interior architecture is constructed on many internal levels of narrow corridors, small rooms and cells, arranged in separated units referred to as "galleries." The inward-canted exterior walls of the buildings surround an architectural nucleus of organized stone-and-earth fill that encloses kilometers of passageways: gallery corridors that turn at right angles, interlaced by horizontal ducts, often many meters above the extensive subterranean canal system of stone-lined drains that potentially served various functions (Lumbreras 1974; Lumbreras *et al.* 1976). In its valley location in the Peruvian Andes at about 3,180 m above sea level, the site occupies the southern end of a visually central river plain (400-500 m wide by about 2.5 km long) that has been extensively shaped by humans across time (Diessl 2004; Kembel and Rick 2004; Contreras 2007; Sayre 2010). From the perspective of modern linguistic reference, the name Chavín plausibly derives from Quechua language "Chawpi, Chaupin," which indicates "central point," "center," "middle," or plural possessive "half" (Parker and Chávez 1976; Pino Durán 2005; Anonymous 2008), a place of union and centrality.

The story of Chavín is continually reconstructed as new evidence strengthens the case for the "Chavín Horizon," an epoch and communication sphere of peoples and sites constituting a large region (Bennett 1943; Willey 1951; Burger 1988; Kembel 2008). Whereas Julio C. Tello introduced Chavín to the modern age as "the Mother Culture" of Andean civilization (Tello 1960), such a tidy origin myth cannot account for the strong identities of other monumental sites that appear in iconographic depictions on ritual objects found at Chavín: for example, on *Ofrendas* ceramics and engraved on the Chavín *pututus* (Lumbreras 1993, 2007; VanValkenburgh 2003). Chavín's widespread influence is best explained by John Rick, who posits that the substantial resources required for the complex's continuous and lengthy development were commanded by an authoritative elite who demonstrated and controlled spiritual access at the site (Rick 2004, 2008; Kembel and Rick 2004). Specialist contribution in craft, labor, and materials was necessary to produce the monumental architecture and associated fine work in stone, bone, shell, and ceramics. The site complex, wielded as a multi-sensory venue, would have been a place where convincing experiential manipulations impressed visitors. Pilgrims would receive knowledge and cult inclusion through participation at Chavín, a credential giving them heightened status at their home sites. Through this process, Chavín values would be strengthened throughout its region of influence, as evidenced in part by the geographical dispersion of its iconography.

A confluence of material factors supports the

Fig. 2 Building "A" at the Chavín ceremonial center. Stone and earthen mortar construction characterizes Chavín monumental architecture. Photo by José Luis Cruzado Coronel.

argument that sensory experience was integral to Chavín. The complex is situated below towering hillsides in a geographically focal plain, at the intersection of two rivers (Contreras 2008). A person within the site is overwhelmed by its monumentality as much as by the surrounding landforms. Within the exterior spaces in the complex, one is enclosed by Chavín architecture; Chavín physically isolates its visitor from external experience (Rick 2006a, 2006b, 2008). Within this architectural landscape, ritually related elements leverage sensorial impact. Artifacts illustrate psychoactive plants, and include the tools used to process and ingest them (Tello 1960; Cordy-Collins 1980; Burger 1988; Rick 2006a; Torres 2008). Iconography depicts transformed humans morphed with powerful animals, and portrays facial features typical of users of psychotropic plant substances. Interior architecture, enclosed by meters of organized stone-and-earth fill, is characterized by confined spaces that often seem subterranean, even when located meters above terrace or plaza levels. These "galleries" are composed of long, narrow corridors and staircases, which direct occupant movement through multi-level, maze-like constructions which can disorient (Kolar, forthcoming). Numerous ducts interlace the complex, provide external light entry, and permit the manipulation of lighting (Rick 2008; Kolar, forthcoming). These ducts also enable sound transmission and modification; as airflow conduits, they facilitate movement of smoke, and scent (Rick 2004). Other architectural features produce areas of strong acoustic resonance and modify sound level and quality (Abel *et al.* 2008; Kolar, forthcoming).

The possibility that Chavín architecture was designed with acoustic intention was first presented by Luis G. Lumbreras in his excavation report of 1974, followed by the article "Acerca de la Función del Sistema Hidráulico de Chavín," published in collaboration with Chacho González and Bernard Lietaer in 1976. In this work, the authors posit that elements of the Chavín canal/drainage/gallery system served acoustic-hydraulic functions, and further suggest that the site's interior architecture can be viewed as a system of "resonance rooms connected by sound-transmission tubes," whose sonification would be driven by moving water (Lumbreras *et al.* 1976: 14-15 [transl. Kolar]). Their physical test of the "acoustic canal," in which two 200-liter cylinders of water were poured through the 45-degree terraced-floor canal underlying the principal staircase of the Circular Plaza, produced a sound effect that observers described as "a crowd applauding [...] in no way associated with a torrent [of water]" (*ibid.*, 35 [transl. Kolar]).

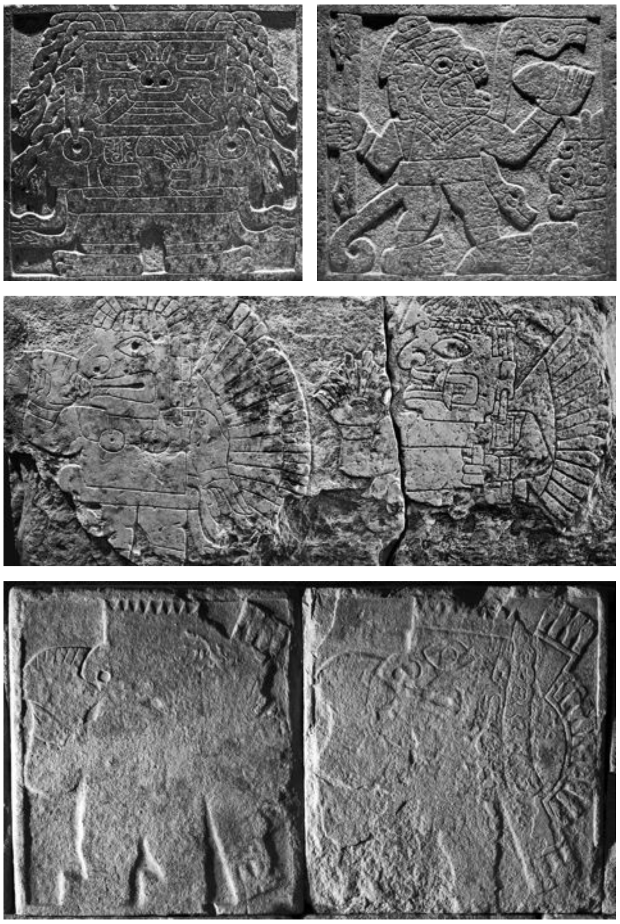

Fig. 3 Site-excavated iconography representing pututus: (a) "Principal deity"; (b) "Monkey-trumpeter"; (c) Cornice fragment, with figures holding pututu (Strombus) and mullu (Spondylus); (d) Pututu players on Circular Plaza facing-stones. Photos by Miriam Kolar and José Luis Cruzado Coronel, from locations at both Museo and Monumento Nacional Chavín de Huántar.

Subsequent acoustic investigation commenced with our project in 2007, when John Chowning, a renowned composer and inventor of computer music technologies, started a dialogue with John Rick after reading about his team's 2001 discovery of the first group of intact, musical/sound-producing instruments at Chavín, the *Strombus galeatus* shell horns. The ensuing discussions initiated our archaeoacoustic collaboration out of Stanford's Center for Computer Research in Music and Acoustics (CCRMA).[2] This research has founded the authors' developing, integrative approach to studying the instruments and sound environments of ancient sites, with Chavín as an exemplary case study.[3] We began with preliminary acoustic measurements of its interior spaces (Abel *et al.* 2008), followed by a measurement-based, sparse computational acoustic modeling proposal (Kolar *et al.* 2010), acoustic measurements and analyses of the Chavín *pututus* (Cook *et al.* 2010), and novel research connecting the physical dynamics of spatial and instrumental acoustics with human auditory perception, though on-site psychoacoustic experiments with human participants (the doctoral dissertation research of Miriam Kolar). Chavín archaeoacoustics research continues, building on the work presented here.

Given the abundant evidence for a multifaceted ritual context in ancient Chavín, including playable shell horns and extant architecture, what objective data can be gleaned regarding how these instruments might have been used three thousand years ago? In our research, we combine several investigatory approaches, in varying order: (1) interpretation of graphical/iconographic representations; (2) physical and acoustic analyses of the artifact shell horns; (3) comparative-ethnographic surveys of similar aerophones; (4) observational tests in associated contexts using modern replica shell horns also made from *Strombus galeatus*; (5) acoustic analyses of associated spatial contexts; and (6) contextualized psychoacoustic experimentation with recorded artifact or replica shell horn sound stimuli. In combining these forms of evidence, our research is guided not only by observation and inference, but by an understanding of the physical and perceptual dynamics inherent to sound production and reception by humans. The site's architectural acoustics and environmental dynamics provide the physical context in which to explore and consider the possibilities for instrument sound production and handling.

2 On-site work approved by the Ministerio de Cultura del Perú, within the Proyecto de Investigación y Conservación Chavín de Huántar, directed by John Rick and Luis G. Lumbreras.

3 Scarre and Lawson (2006) give detailed examples of other archaeoacoustic studies and approaches.

The Chavín *Pututus*: Ancient Sound-Producing Instruments

The evidence for musical/sound-producing instruments from ancient Chavín was, until recently, primarily derived from its numerous depictions of the marine shell aerophones formed from gastropods of the *Strombus* genus. These instruments are known as *pututus* in contemporary Peruvian Andean usage, and in Quechua, *huaylla qquepa* or *waylla kepa* (and various other spellings), with a variety of meanings including "shell trumpet," "dance trumpet," and "greening trumpet" (Paulsen 1974; Anonymous 2008; Herrera 2009; Peterson and Brooks 2010). The importance and use of *pututus* in Chavín culture, whether as ritual objects and/or sound-producers, is codified in many instances. The *pututu* adorned with eye and mouth common to Chavín serpent-head iconography is centrally featured on the "Tello Obelisk" (Tello 1960). *Pututus* are held by relief-carved figures on two separate facing-stones found in the "Atrium of the Lápidas" (near the portal of building "A"; see Lumbreras 2007: 86): a facially featured, fanged *pututu* is held in the right hand of the "principal deity" or "Smiling God" (descriptive name per Rowe 1962), who also holds in its left hand a spiny/thorny oyster or *mullu* (*Spondylus princeps*) (Fig. 3a), and a silhouetted *pututu* is raised high by the "monkey-trumpeter" (descriptive name per Lumbreras 2007: 90) (Fig 3b). Other instances show individuals holding *pututus* raised as if to be blown, organized in contexts that suggest processional performance. A figure on a cornice fragment discovered in 1998 has been joined to lead a previously known fragment that depicts a figure holding a *Spondylus* shell (Rick 2004, 2008) (Fig. 3c). Two *pututu* players are featured in low relief on in-situ facing-stones lining the north-western interior wall of the Circular Plaza (Lumbreras 2007) (Fig. 3d).

Unique forms include a singular ceramic, whose high-relief *pututus*, shown with serpent-like heads extending, alternate with groups of *Spondylus* (Fig. 16). This piece, initially interpreted to represent live animals in the sea (Lumbreras 1993, 2007), inspires an alternate interpretation, proposed later. The most detailed depiction known is the silver and gold metal "snuff spoon" of uncertain provenience (Lothrop 1951), made of 22 pieces of worked metal (Burger 1988, 1996; Quilter 2005), whose subject is a seated *pututu*-playing personage with distinctly large ears (Fig. 4).[4] The rolled-construction, three-dimensional metal representation of a shell horn is pressed to the lips and held between both hands of the player, parallel to the figural base, with its bell/shell lip opening pointing right. The crafted shell lip enveloping the player's hand is a detail not shown in other illustrations that mirrors a preference of

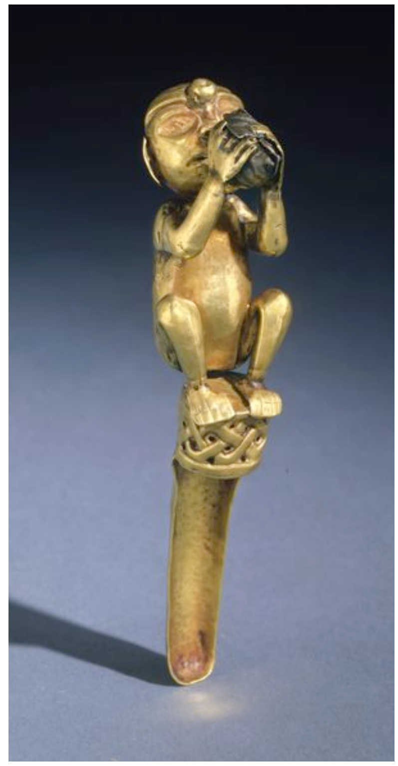

Fig. 4 Bimetallic effigy spoon (and potentially rattle) PC.B.400, gold and silver, 11.1 cm, possibly from Chavín de Huántar. The three-dimensional representation shows a functional pututu playing orientation and handling style. Image copyright Dumbarton Oaks, Pre-Columbian Collection, Washington, D.C.

4 Note that while this effigy spoon tantalizes the imagination in its stylistic and thematic connection to Chavín, since its provenience is uncertain, we include this little-understood piece because it is ubiquitous to Chavín literature.

Fig. 5 Chavín pututus: well-formed mouthpieces and v-shaped notches to the upper apical lip are characteristic of the 20 Strombus galeatus instruments excavated at Chavín de Huántar by John Rick and team in 2001. Photos by José Luis Cruzado Coronel, from the collection of the Museo Nacional Chavín.

modern Andean *pututu* players. Might this representation indicate ancient instrumental playing practice? In his extensive description, Burger (1996: 56, 61) mentions that the spoon contains "tiny pellets [...] made of a low-density material [...] so that it could also function as a rattle"; it is worth noting that this piece may indicate another class of ritual sound-producing instrument associable with Chavín.

Several qualifications are in order regarding the representation of *pututus* in Chavín iconography. First, because of the complexity of symbolic representation, iconography should not be considered direct documentation (argued cogently by Thomas and Kelly 2006). From an interpretive standpoint, recognition of the stylistic range in examples along with incomplete iconographic context presupposes caution in assuming depiction of ceremonial or performance practice. Despite these caveats, we argue with confidence that the variety and prominence of site-excavated representations of *pututus* indicates the importance of these marine shell objects to Chavín, both as ceremonial symbols and sound-producing instruments.

Only fragmented remains of *Strombus* marine shells had been encountered at Chavín, notably in upper strata of the thus-named *Caracolas* Gallery, until its further excavation in 2001 that produced of a group of twenty intact, engraved, playable *Strombus galeatus* horns. This was a pivotal find that further related previously excavated shell fragments with the numerous graphic depictions of whole shells and instruments, and established a plausible ancient storage location. These Chavín *pututus* (Fig. 5) are marked by substantial handling wear, suggesting multi-generational persistence (Rick 2008). Each bears a distinctive v-shaped cut to the outer apical lip, notably excised following the application of iconography to the full-grown shells, because any decorations in this zone are always marred by this cut. The stylistic diversity of iconography among these shell horns connects them to a range of sites affiliated with Chavín (analysis presented by VanValkenburgh 2003). While all the Chavín *pututus* are aerophones of similar physical design, especially in their formal handling (rounded and polished contours; mouthpieces filed directly into the shell bore; "notched"/v-shaped apical lip cut; small distal end holes for ornamentation/handling strap), in their diverse engravings they project specific identities of differentiated sites, individuals, or groups. Within a structured ritual setting where conformity was necessary for many ends, these decorations evince that distinctive identity was also valued, projected, and preserved through time in these objects.

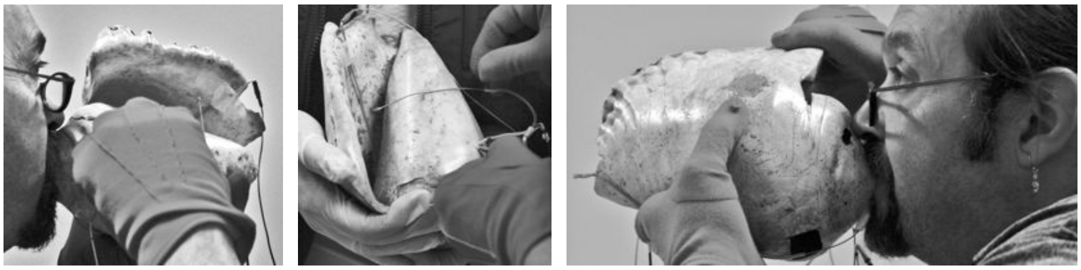

Fig. 6 Acoustic measurement of pututus at the Museo Nacional Chavín, 2008: (a) Cook stabilizing mouth-located microphone in shell horn prepared with 4 sequential microphones; (b) Placement of microphones inside shell and at bell opening; (c) Cook blowing into a pututu with bore holes likely from stress damage. Photos by José Luis Cruzado Coronel (a, c) and Jyri Huopaniemi (b).

Evaluating the Sound-Production Potential of the Chavín *Pututus*

Initial acoustic evaluation of the Chavín *pututus* was made by John Rick and David Lubman, who measured levels around 111 dBA at 1 m from the instrument, and estimated a long-distance reception range exceeding 4 km, not taking into consideration environmental and landform interaction effects (Rick and Lubman 2002; conference paper presented by Lubman and Rick 2002). Their study provided important insights about the instruments' sonic potential, and indicated the utility of making future comprehensive and contextualized analyses. In 2008, our archaeoacoustics team made physical examinations and acoustic measurements of 19 of the 20 intact site-excavated shell horns (those on display at the Museo Nacional Chavín).[5] We also recorded and studied the *pututus* as handled and played by Andean instrumentalist and scholar Tito La Rosa, who provided an intuitive, performative complement to the measurement process. We began our study of Chavín *pututu* sound production by documenting the acoustic characteristics and playability features of these instruments, with follow-up signal processing analyses led by Perry Cook and Jonathan Abel (Cook *et al.* 2010).

Measurement of Acoustic Characteristics

In acoustic measurement of the ancient *pututus,* we sought to characterize each instrument's sounding frequencies (the tones or "pitches" readily produced by blowing, specified in acoustic cycles per second, or Hertz, abbreviated Hz) and overall spectral response, as well as acoustic impedance (a measure used to understand how the physical dynamics of the interior or *bore* shape of the instrument relate to its sound-producing potential, necessary for computational modeling techniques), and acoustic radiation pattern (the directionality of sound leaving the instrument). The measured data and recordings from these shell horns provide material that can be used in modeling applications, as well as for loudspeaker playback in on-site tests and psychoacoustic experiments. In addition to generating acoustic analytic data from the Chavín *pututus*, we have tested and measured modern shell horn replicas to verify their similarity. From these studies, we maintain that full-size modern *Strombus galeatus* horns, with or without the characteristic v-notch, are suitable substitutes for making observational tests and measurements in site contexts and laboratory settings, as their acoustic characteristics are within the same range as the site-excavated instruments.

First, we recorded the intrinsic sound-production capability of the site-excavated *Strombus* horns as produced by Cook (Fig. 6). For the 19 available Chavín *pututus,* which range in size, we found that player-blown tones had fundamental frequencies ("H1") ranging from about 272 Hz to 340 Hz. To give the reader a modern musical

5 These measurements were guided by the musical acoustics researcher and experienced shell horn player Perry Cook, in collaboration with a team of musically trained engineers: Miriam Kolar, Patty Huang, and Jyri Huopaniemi, and documented in video by Cobi van Tonder and José Luis Cruzado Coronel.

analogy, these frequencies can be related to common practice notes from approximately "middle" C#4 to F4, when A4 = 440 Hz. These frequencies were measured with the player covering any holes that were found in the bore area of some shells. Rick's examination suggested that these holes were likely formed after the instrument use period, by weathering and/or stress around decoration lines, or in thin areas of the shell wall (e.g., the instrument shown in Fig. 6c), rather than intentionally created by the instrument-makers as tone-shaping structures. To test this theory from the perspective of instrumental practice, we measured the acoustics of any such *pututus* with these holes left open, which frequently resulted in reduced playability. The lack of sonic utility of these structures supports the interpretation that such holes are degradations rather than crafted instrument features. The player-blown measurements, using a range of customary and extended techniques, show that the *pututus* readily produce a second harmonic, "H2", (or first "overtone") roughly double the fundamental frequency, about 553 Hz to 696 Hz. Other blown acoustic excitations were used, including noise injected into the bore by the player blowing through constricted lips, and a lip "fry" signal, a non-periodic chain of near-impulses. These extended-technique excitations, as well as the second-harmonic production, are important to the comprehensive documentation of the sounding potential of the instruments, to thoroughly characterize each instrument's spectrum, the physical basis for its perceived timbre or sound quality.

The Chavín *Strombus* bore impedance measurements were taken using impulses generated by slapping (and holding in place through the sound decay) an open, flattened palm of the hand against the mouthpiece, which provides an acoustic excitation not related to performer embouchure and generated airflow quality. This gives a measure with which to cross-check the neutrality of the frequency measures generated by playing the instruments, and also to quantify the third harmonic, "H3", (or second "overtone"), which is more difficult for a player to consistently produce. The third harmonic is an important spectral characteristic in the timbre of an individual instrument, and thus adds to the frequency data set for a horn. The measured spectral data from these impulse measurements verified the player-blown data, showing a slight increase in frequency across the instrument group, which indicates that player input does affect the frequency output of the instruments, as expected from its physics: the player's lip, when coupled and oscillating, serves to slightly decrease the fundamental (or resonating harmonic), due to the mass of the lip (Fletcher and Rossing 1998). It is well known from musical acoustics research that shell horns are "lip-reed" aerophones that produce sound because the player's lips vibrate at a frequency determined by bore and lip interaction dynamics: the vibrating lips function as a "pressure-controlled valve" that opens and closes, sending rapid puffs of air into the instrument with precise timing that allows tonal continuation, due to acoustic feedback (see Fletcher and Rossing 1998; Rossing *et al.* 2002). Thus, impedance characterization of the bore gives a record of the instrument form that interacts with player technique in order to produce sound. The bore impedance measures also verify our assumption that the Chavín *Strombus* bores all share the exponentially flaring spiral form, and thus, these shell horns can all be considered various-sized instruments of the same family. This is consistent with the observation that the shells are all specimens of *Strombus galeatus* gastropods.

Our instrument-internal multi-microphone measurement technique (Cook *et al.* 2010) used to record all measured acoustic excitations allowed us to capture spatially sequential moments of each sounding event, as the excitation passed microphones (1) in the player's mouth (only for blown measures), (2) in the instrument's mouthpiece, (3) inside the bore, and finally (4) at the end opening of the *pututu* bell (the external lip of the shell) (Fig. 6b). For the blown measures, the mouth-located, 2.5 mm-diameter Countryman E6 omnidirectional microphone is anticipated to create a small effect on the airstream and impedance measurements, which will be explored in future research suggested by Cook. These multi-microphone measurements give an individual map of the internal acoustic and physical contour of each instrument, the "area function," which can be viewed as a linear graph showing how the instrument bore varies over its length from the ideal exponential flare (see examples in Cook *et al.* 2010). This data is essential for our planned computational physical modeling techniques, with the added benefit of identifying internal malformations and indicating any natural or deposited obstructions. In some research contexts, such acoustic characterization of the bore could provide a cost-effective alternative to medical scanning, which is frequently unavailable in remote

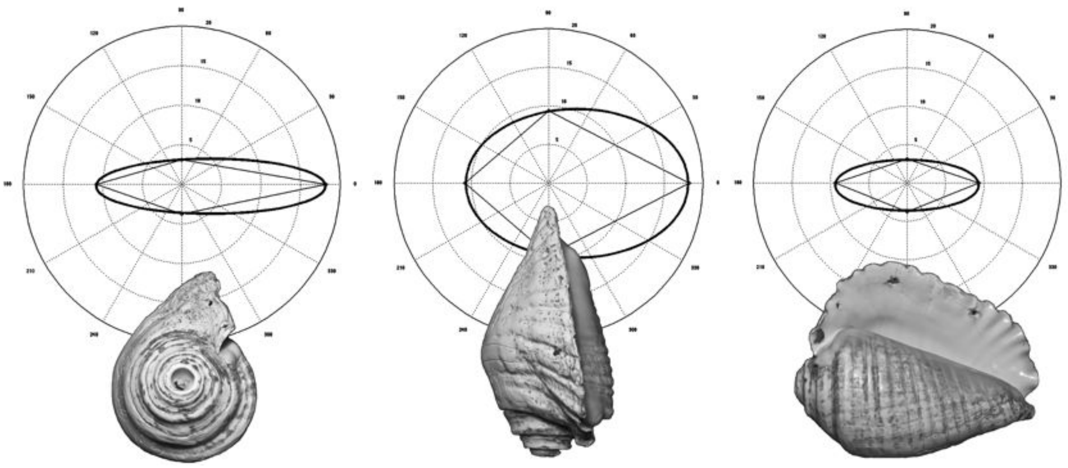

Fig. 7 Acoustic radiation pattern (sound energy directionality) for Chavín Strombus #2, with pututu performer located at the center of each polar diagram. Insets of a modern replica Strombus horn indicate orientation. Gross directional measurements (from 6 coordinates) were made at the Museo Nacional Chavín, Sept. 2008. Diagram by Miriam Kolar 2012 (adapted from Cook et al. 2010).

field locations (such as Chavín) or may otherwise be logistically prohibitive, though both techniques used in conjunction would offer the most complete data set.

The instrument's acoustic radiation pattern, a measure of the directionality of sound energy it produces, is an important characteristic that influences its interaction dynamic with external acoustics. We measured the acoustic radiation from each of the Chavín *pututus* by arranging six omnidirectional microphones around the player in a configuration approximating coordinates of a 1 m-sphere, to record the sound energy above, below, in front of, behind, and to the left and right of the player with instrument. To estimate the overall directionality across frequencies, we compared the signal received by each external microphone to the microphone located at its bell. As expected, the greatest amount of sound energy radiates directly from the bell opening (in our chosen instrument handling orientation, toward the right), while the least energy exits at the mouthpiece end (since the player's body absorbs and reflects energy forward, and substantially blocks backward-radiating energy). In proportions specific to each horn, the remaining energy radiates up, down, and to the left; Fig. 7 shows the estimated radiation pattern of one of the measured Chavín *pututus*. Although further measures using more microphones could better characterize details in the radiation pattern, especially as a function of frequency (high frequencies are typically more directive than lower frequencies), these measurements give a general understanding of acoustic directionality, a parameter that affects how these *pututus* can be employed in interaction with environmental acoustics. For example, if a player orients a shell horn such that its bell opening faces a relatively flat, unobstructed surface, such as stone walls at Chavín, the emitted sound will reflect directly, reinforcing the sound. Such orientation techniques can also be used to manipulate a listener's perception of sound source distance and direction, based on geometrical relationships relating environmental features, player, and listener.

Performance Practice Evaluation

The performance practice of musical/sound-producing instruments is related to their functional characteristics, varies with cultural preferences, and is influenced by feedback from environmental acoustics and social dynamics. In order to understand the functional possibilities for performance of the Chavín *pututus* in estimated ancient settings, we gather use evidence from the site-excavated shell horns, and seek comparative data from modern practice with similar instruments.

An examination of non-acoustically relevant physical characteristics of the instruments provides some indications regarding their handling.

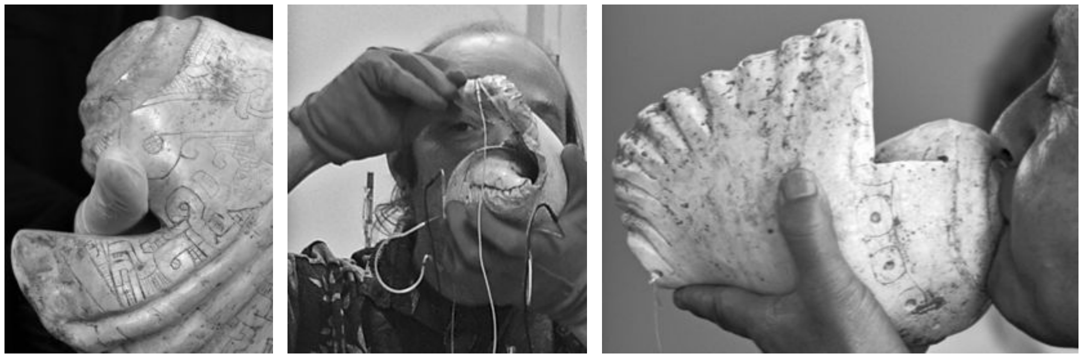

Fig. 8 *The characteristic "Chavín cut," a v-shaped notch in the upper apical lip of the Strombus galeatus shell horns. Perry R. Cook (b) and Tito La Rosa (c) demonstrate instrument orientation. Photos (from left) by Jyri Huopaniemi, Miriam Kolar, José Luis Cruzado Coronel.*

Since all the Chavín *pututus* exhibit substantial use-wear, a more detailed study of these handling marks and mouthpiece wear might corroborate or challenge hypotheses formed from other evidence. Cook has initiated such an analysis based on measurement session photos, while Kolar noted from visual inspection of the instruments that the mouthpiece area of flattest wear seems to coincide with bottom lip placement if the shell horns are oriented bell-right (detailed later in this section, and shown in Fig. 9a). Physical wear to the mouthpiece during playing, related to the relatively greater mass of the bottom compared to top lip, is a plausible mechanical explanation; this wear pattern is corroborated by VanValkenburgh (2003), who attributes it to an observed behavior of modern players resting or supporting *pututus* on the bottom lip. The v-shaped notch (see examples in Fig. 8) borne by all Chavín *pututus* is specifically associated with Chavín: the other adequately contextualized examples of *Strombus* horns having similar cut-outs to the upper apical lip are instruments from the culturally and temporally related site, Kuntar Wasi (*ibid.*). Other than having an unknown symbolic relation, what could be its function? VanValkenburgh has identified this cut as a "handgrip" (Fig.8a), documenting five distinct types; indeed, shells having such a lip cut are more readily secured between the fingers and thumb. It has also been suggested that this cut could enable deeper insertion of the hand for tonal shaping (Cook *et al.* 2010). While such hand-insertion by a player does change acoustic reflections in the bore/bell, from a functional standpoint, it rapidly damps sound production rather than producing a range of tones. Kolar has observed from experimentation with modern replica *Strombus* horns that hand-entry nearer to the opposite, smaller distal end of the shell allows a range of tone shaping with less likelihood of unintentionally silencing the instrument when pitch modulation is the performance goal. In ethnographic comparison, we have observed that contemporary Andean players of the instrument, such as expert Tito La Rosa, employ distal-end tone shaping as a performance technique.[6] We maintain that this technique relates to a morphological characteristic of these instruments, and thus should be cataloged as a possible ancient practice component, rather than an imposed modern aesthetic.

Another functional purpose for the upper apical lip cut might be to clear the player's line-of-sight, enabling visual communication when the instrument is held to the player's mouth, with the shell lip pointing upward and bell opening to the right, as noted by Kolar during our team's 2008 measurement sessions (Fig. 8b). Visual communication would be important for certain ritual contexts, situations in which sighted coordination of soundings with events, or among multiple players, was necessary. Enhanced frontal vision could be important for procession, or for other player movement executed with the instruments raised in front of the face. Cook has observed from his experimental crafting of modern *Strombus*

6 See Tito la Rosa for a performance example (https://ccrma.stanford.edu/groups/chavin/video/TitoLaRosa_pututumodulation_2008.m4v).

pututus, that due to the physical form of some shells, such notching is necessary to remove excess shell material in order to make space for getting one's face close enough to the mouthpiece to play the instrument. The larger the player's nose, the more shell lip must be removed. While direct reading of iconography is cautioned, prominent noses and corresponding large *pututu* notches can be seen in Chavín relieves of figures with *pututus* raised as if blown (see Fig. 3). Another interpretation is that these notches might be necessary if players wore masks, headgear, or other decorations that extended forward. The exaggerated size of the notch in some instruments can be seen in Fig. 8c.

Questions of functionality, applied to ethnographic comparisons, can provide information regarding the sounding characteristics and playing orientation of instruments with respect to players and surroundings. Playing orientation of the *pututus* might be realistically depicted in site iconography: both experienced aerophone players and novices presented with the artifact horns during our 2008 measurement sessions elected to position the shell horns up and away from the body, centrally in front of the face, parallel to the floor, with the bell facing right, lip up, such that the definitive v-notch provides a frontal line-of-sight for the player (Fig. 9a). In this position, the shell can be entirely supported with the left hand, thus freeing the right hand for tonal/timbral shaping, as attempted by the more experienced players. This is also the orientation depicted on the sculptural metal snuff spoon/rattle (Fig. 4). From a functional standpoint, such a playing position lends itself to processional movement and sound projection into the distance.

An ethnographic comparison with local Andean players of modern shell horns corroborates the ground-parallel, bell-right handling technique, and demonstrates a popular alternative. Though the initial position is favored for processions and presentations at large group events, where the player's stance demands visual and perhaps theatrical importance, a second orientation positions the shell between two hands, closer to the chest, with its bell opening turned upward (Fig. 9b). In this case, the bell is rotated upward 90 degrees or so from the bell-right position, and the instrument tip may be angled down toward the ground. This alternative handling focuses player technique on embouchure and breath-based tonal and timbral modulation, as it does not allow manual tone shaping since both hands are employed as supports. An alternative modern playing style, also observed in contemporary Chavín, positions the mouthpiece at the corner of the mouth, with the instrument bell pointing right or up, but the entire shell extending sideways from the player's mouth instead of axially aligned (Fig. 9c); in the literature, this practice was documented more than fifty years earlier in the southern Peruvian sierra (Hilton 1964: 82); Rick has corroborated his ongoing observation of this technique across the Andes. Such orientation provides a frontal line-of-sight to players of instruments not excised with the v-shaped notch.

Specific sonic effects are produced by instrument playing orientation, for both player and listeners, because of the *pututu's* non-uniform acoustic radiation pattern. In the first example (bell-right, ground-parallel, shown in Fig. 9a), sound radiates primarily to the right of the player, with less energy and substantially less high-frequency energy radiating to the other directions. This is the position which offers greatest directed distance projection, and would be best suited to performance in outdoor contexts, and to settings

Fig. 9 Pututu playing orientations demonstrated by José Luis Cruzado Coronel with replica Strombus shell horn: (a) Bell-right, ground-parallel; (b) Bell-up, two-hand-grip; (c) "Sideways," mouth-corner-angled. Photos by Miriam Kolar.

in which the player performs above large areas to listeners in various locations, such as Chavín plazas, or projects sound throughout the surrounding valleys. A player using the second orientation (bell-up, two-hand-grip, shown in Fig. 9b) receives more sound directly from the bell, because sound radiates primarily ahead of and above the player, whose body serves as a symmetrically positioned sound absorber/reflector. Such use is more practical for performance in enclosed surroundings, for intimate events in which distance projection and any visual effect from the player's stance are precluded; for example, in interior, seated performance. Tests with replica *Strombus pututus* in Chavín galleries demonstrate that such handling produces a strong initial ceiling reflection that can create binaurally consistent early reflections for a nearby listener located on-axis. The alternate mouth-corner orientation (shown in Fig. 9c) directs sound away from the facing direction of the player, providing an unobstructed frontal line-of-sight for the player. Such an orientation might be employed in order to disassociate, for listeners, the acoustic reflection sequence from its source, depending on the angles and distances of surrounding reflective surfaces, as discussed in the following example.

The non-uniform acoustic radiation pattern of the *pututus* enables a selectable directivity of sound energy: a player may orient the shell horn in relation to listeners and acoustic features of the surroundings, in order to shape the presentation and influence listener reception of sound. This characteristic has implications especially for performance in small or enclosed spaces (such as gallery interiors), where establishing the directionality of initial early reflections may be used to manipulate the perception of sound source location for listeners, dependent on relationship of source and listener within architectural geometries (Kolar, forthcoming). We have tested the following example: a *pututu* player stands in a gallery corridor and plays a tone, having angled the instrument's bell to direct its sound at a point on the wall opposite a ventilation shaft that connects the corridor to a separate room. The initial acoustic reflection enters the duct directly, but the player is standing farther down the corridor so as not to appear at the duct opening for a person in the room who could be looking through from the duct's opposite end. Thus, the player can disguise his or her visual presence while manifesting a sonic presence without obvious source, which could have been elemental for ritual practices based on manipulation of sensory experience, as posed by Rick. This ventriloquist-like tactic could have been used to separate sonic and visual stimuli, or to create other illusions. Many such sound manipulation techniques are possible given the directive acoustics and sonically coupled rectilinear geometries of gallery architecture (Abel *et al.* 2008; Kolar *et al.* 2010), and the strong acoustic directionality of the *Strombus* horn bell (Cook *et al.* 2010).

Acoustic Dynamics of Site Settings

An empirical understanding of the dynamics between instrument and spatial acoustics can be developed through observational tests, measurements, and comparative study. In September 2008, we began on-site investigations of acoustic contexts, using replica *Strombus* horns and other Andean musical instruments. With experienced and novice performers, we explored and recorded the effects of extant acoustics in intimate spaces (galleries) and mid-range areas (intra-site spaces such as exterior plazas), and for distance transmission (with landforms of the river plain and surrounding valleys). These preliminary tests have guided subsequent objective measurements, discussed here, and suggest future research, especially in computational modeling to reconstruct ancient structures and conditions.

Exterior Acoustic Dynamics

Where instruments could have been played in ancient ceremonial contexts can be proposed based on an appraisal of the acoustic characteristics of architectural and geographical environs, combined with a functional analysis of the characteristics of exterior architecture, specifically what their dimensions and layout suggest about human occupancy and movement. Kembel (2008) and Rick (2004) have postulated relationships between architectural forms, construction sequence, and group dynamics; Moore (1996) has also offered insights regarding Andean ceremonial complexes based on site characteristics, especially in relation to human visual perception. Other contextual clues exist; for example, graphical representations of instrument players, as in reliefs lining the Circular Plaza (shown in Fig. 3d and indicated in Fig. 12b), or instrument materials excavated at a specific location, such as the *pututus* discovered in the *Caracolas* Gallery that is located alongside the Circular Plaza. The exterior architecture of the Chavín complex is characterized by large, open spaces, terraces and plazas surrounded by high buildings, a formal layout conducive to one-to-many address, processions, and antiphonal performance, which would situate *pututu* players atop buildings for optimal interaction with mid-range (intra-site) and distance (environmental) acoustic features. Because Chavín's exterior architecture is substantially degraded from its ancient forms, observational tests and acoustic measurements of its extant structures cannot fully or accurately characterize the ancient acoustic environment. Some large-scale dynamics should be preserved in the extant site, such as reflections/echoes from building faces, low-frequency resonances between buildings, and certain staircase effects. However, the sound environment of the existing exterior is assumed significantly different from those during the sequence of fifteen or more ancient construction phases documented by Kembel (2001). In-progress computational acoustic modeling of exterior architectural acoustics is developing virtual reconstructions to enable tests that current conditions prohibit, with the longer-term goal of surveying changes in site acoustics across time.

Comparative estimations of some ancient acoustic features can be made by referencing studies by archaeoacoustics researchers in sites having similar architectural forms. Mid-range acoustics of monumental architecture characterized by high stone buildings with sunken plazas has been studied by Sergio Beristain, who estimated and measured sound transmission in Mesoamerican sites to understand and parameterize the one-to-many aural communication dynamic from individuals situated on building tops, to crowds gathered below in plazas. His example scenario is appropriate to Chavín: "In an open space, like in front of a Pyramid or a tall basement [sunken plaza], some 15,000 to 20,000 standing people can be comfortably accommodated within a floor area of 100 x 100 mts., where the farthest person would be located at just little over 110 m. away from the speaker [on top of the pyramid], considering him to be within at an angle of 30 degrees to either side from the main axis of the speaker voice radiation, so this is a kind of a crowd that a single person can address without the use of electronic amplification, provided there are no obstacles or intruding noise. [...] It can be concluded that the higher the platform, the longer the useful distance, up to a practical maximum of some 120 m. due to the effects of atmospheric conditions [...] and noise" (Beristain 2010). The Square Plaza at Chavín is half the size of this example, and accordingly, sound transmission from a person atop the adjoining building "A" (Fig. 2), or one of its now-hanging staircases, should adequately reach a group assembled within the plaza, and potentially carry east across the north-flowing Mosna river to the ancient residential area referred to as "La Banda" on the other bank. Researchers' observations, made while working outside in the complex, verify auditory reception of music and conversation (though without clarity of speech) from groups of people located on these and other adjacent hillsides. Thus, site exterior acoustic transmission plausibly extends to a larger valley context, up to longer-distance dynamics, as demonstrated by the following study.

We have evaluated the large-scale sound transmission potential around Chavín in its extant condition. Tests using replica *Strombus* horns performed from the tops and staircases of Chavín buildings, and on its terraces overlooking plazas, produce audible and similar-sounding echoes among elements of site architecture and the surrounding valley hills, which extend up and away from the approximately 400 to 500 meter-wide river plain setting (Diessl 2004). To quantify longer-distance acoustic effects, Kolar recorded and measured these echoes between *pututus* performed on the complex and landforms in the valleys surrounding the Chavín complex. From general locational data reported by Diessl, it is possible to estimate the physical span of echos generated between complex locations atop buildings "A", "B", and "C", and corresponding landforms. For example, between the "Castillo UTM: 261.2 km E, 8939 km N" and the prominent rock feature "Shallapa UTM: 261 km E, 8939.5 km N, 3300 m alt." (*ibid.*), the approximate airborne distance of 200 m requires an acoustic round-trip of 400 m to hear or record an echo received near the sound production location. By recording the ambient temperature and humidity at the time of echo testing, an accurate speed of sound can be calculated (sound speed in air is affected by humidity and temperature, but not altitude, Rossing *et al.* 2002: 47). From the audio recording, the echo duration can be computed, which together with the ambience data, allows a close estimate of the physical distance between instrument player and contributing landform reflecting surface.

One such distance-acoustics measurement is described here. On 12 September 2011, at 5 pm, the documented conditions were 41% humidity, 16 degrees Celsius, which gives a speed of sound

Fig. 10 Chavín Circular Plaza (approx. 20 m diameter), with its principal staircase (center) aligning building "B", on top of which pututu players were located for echo tests with the Shallapa bedrock face (upper right). Pututu-player reliefs (detailed in Fig. 3d) can be seen in their excavated context on the plaza wall under the modern roof (right of principal staircase). Photo by José Luis Cruzado Coronel.

about 341 meters per second. Two replica *Strombus* horns were played atop buildings "A", "B", and "C", with varying tone durations and bell orientations. Similar-sounding echoes were observed from all directions, including a 360-degree motion effect. Echoes with observed durations of 6 seconds indicate a sound transmission path totaling more than 2 km: this sound event confirms the plausibility of *pututu* tone reception as far away as 1 km. Analysis of the recorded waveforms from these measurements verifies acoustic interaction with various landforms, notably the *Shallapa* bedrock feature,[7] when one *pututu* was played from atop building "B", over the Lanzón Gallery and west of the Circular Plaza staircase. The greatest sound effect was perceived and recorded when the shell horn's bell was oriented west-north-west, toward this prominent rock face (a setting shown in Fig. 10), and the instrument was played with short, articulated "blasts." In the corresponding audio recording, an echo start time is identified 1.234 seconds following the peak of the initial sound event; the distance of the reflection is calculated by multiplying the time difference by the speed of sound (1.234 s x 341 m/s), resulting in a 420 m roundtrip distance for the sound to reach the rock face and travel back to the co-located source/recorder location. Therefore, the acoustically estimated distance between this landform (probably its lowest, closest surface) and the player's location is 210 m, nearly equal to the approximation from Diessl, and further verified using Google Maps to confirm gross distance relationships.

The prominent audible effect of echoes among locations within the Chavín complex and surrounding landscape is exploited by the *Strombus* horns, which can produce distinctive, high-energy sounds that can have sharp articulation as well as several-second duration. Our empiri-

7 For geomorphological information and analyses, see Contreras (2007, 2008).

cal measurements confirm previous calculations, historical data, and anecdotal reports that this instrument can serve as a longer-distance communication tool in an Andean valley setting. Future studies are envisioned in which *pututu* players and recorders will interact among prominent peaks of landforms surrounding the Chavín complex, in order to map and quantify the larger-valley transmission potential of these instruments, calibrated to topographical area maps. Acoustic studies linked to precise geographic information system (GIS) data could illuminate details and enable further calibration of features in recorded audio with specific landforms. Such research, combined with computational modeling that reconstructs ancient architectural, terrestrial, and environmental conditions, will contribute to a characterization of the exterior acoustic environment at ancient Chavín.

Acoustic Dynamics of Interior Architecture

Reliable assessments of interior acoustic features of extant site architecture are readily produced, and consistently reproduced, from measurements of enclosed spaces. The extensive gallery system at Chavín offers the opportunity to make comparative studies across many instances of similar, well-preserved structures. Our study of the interior acoustic environment at Chavín began with preliminary measurements conducted by Rick and others in 2008, and Kolar continues to measure and document gallery acoustics using techniques and equipment optimized for the site's logistical demands and unique features (Abel *et al.* 2008, 2009; Bryan *et al.* 2010), such as functionally separated but acoustically coupled interior spaces (Kolar *et al.* 2010; Kolar, forthcoming).

The acoustics of an enclosed space can be evaluated by making and analyzing an audio recording of the room's response to a mathematically approximated sonic impulse, a sound that contains equal energy for all frequencies. For our purposes, this is limited to the range of human hearing (approximately 20 Hz to 20 kHz) (Zwicker and Fastl 1990) and extending lower, to around 5 Hz (depending on the loudspeaker output capability) to capture frequencies that may not be heard, but are sensed through other physio-psychological processes (Schust 2004). The acoustic measurement technique we employ is to generate an *impulse response* of the space by reproducing a mathematically generated test signal through a calibrated loudspeaker and recording the resultant *room response* using one or more omnidirectional microphones, which can be configured in clustered (Fig. 11a) or spatialized arrays, or binaurally situated in the outer ear canals of a researcher (Fig. 11b). This recording is then converted, using specialized audio digital signal processing techniques, into the characterizing impulse response that can be analyzed to understand the room's acoustic properties and identify likely perceptual correlates (Gade 2007). Key methodological points include the material and duration of the test signal, and the specification of loudspeaker "source" and microphone "receivers," and their positions relative to one another and to architectural forms. For example, the 4-inch single-driver loudspeaker (Meyer MM-4XP) we frequently employ provides a sound source that radiates similar to the plausible ancient sound sources of human voice and *pututu*, and we often position microphones to correspond to possible listener head/ear positions. We have determined that the repeated exponential sinusoidal sweep (ESS), a sine tone sweep starting at the lowest specified frequency and rising exponentially to the highest specified frequency, is better for our application than other impulsive excitations typically used in assessing architectural acoustics (for example:

Fig. 11 Acoustic measurement equipment used in Chavín galleries: (a) 4" single-driver loudspeaker (Meyer MM-4XP) and the "bouquet" microphone array designed by our team (Countryman B6 elements); (b) Binaural recording employs omnidirectional microphones (Sennheiser/AuSIM) positioned in the outer ear canals of a researcher. Photos by José Luis Cruzado Coronel.

Golay codes, filtered noise, balloon pops, spark gaps, starter pistol shots, whip cracks, woodblock clacks). The ESS method offers: (1) superior signal-to-noise ratio, (2) indication of loudspeaker distortion, and (3) immunity to slight temporal variations that result from wind and air current dynamics related to temperature and humidity (Farina 2000, 2007; Müller and Massarani 2001).

Analysis of spatial impulse responses provides information regarding how the measured area transforms sounds propagating within, data that can then be applied to understand and simulate the dynamics between the space and a particular sound source. For example, the narrow corridors and alcoves ubiquitous to Chavín galleries have cross-sectional dimensions that produce audible resonances in the frequency range of the human voice and the sounding tones of the Chavín *pututus*, a result of the reinforcement of sound energy wavelengths of consonant proportions with architectural dimensions. These architectural modal resonances are acoustic vibratory frequencies reinforced by the cyclical reflection of sound between parallel surfaces, thus "tuned" by the spatial dimension. To predict a spatial modal resonance, a theoretical estimation can be made, and if the structure exists, the resonance may be verified empirically by measurement. For an approximation of the spatial fundamental resonant frequency, the lowest tone that is amplified by acoustic reflections between two parallel surfaces, one divides the speed of sound by twice the dimension.[8] For example, in a Chavín gallery corridor whose side walls span 1 meter, the calculation is: 340 m/s, divided by twice 1 m, equals 170 Hz, a frequency that should be amplified. In fieldwork, we frequently incorporate such estimation in our practical scientific process: step (1) researchers visit a site area and make observations; step (2) an explanation based on physical principles is proposed for the noted phenomenon; step (3) an experimental acoustic measurement is designed and implemented to test the theory; step (4) the acoustic data is analyzed, and results are compared with the observation and proposed explanation. Anecdotal reports (e.g., site visitors or historical texts that claim a sound effect) or contextualized questions (e.g., the use of sound to serve a hypothesized ancient function) frequently motivate this process, which can be followed with the interpretation of acoustic data in terms of human auditory perception.

A particularly challenging aspect of archaeoacoustic research is interpretative accuracy in reconstruction. Whereas the exterior architectural features of the Chavín complex have been modified from period conditions by later constructions, degraded and partially covered by landslide events (Contreras 2007), the extant interior architectural forms are considered substantially intact, with the caveat that the irregular stone and earthen mortar of interior wall surfaces may have been covered with clay "plaster" (Tello 1960; Kembel 2001), whose finish could have varied from smooth (given fragmentary *in situ* examples) to worked relief similar to examples in coastal sites, as suggested by Lumbreras and Amat (1965-66). Theory supports that acoustic differences between the extant surface of stone and mortar and a smooth clay plaster covering would be limited to sound frequencies having wavelengths of the same sizes as the unplastered surface irregularities. The differences in height and depth of mortar details and stones, typically from less than 1 cm to around 60 cm, equal a range of frequencies from about 560 Hz to more than the limit of human hearing, higher than the base modal resonant frequencies related to architectural dimensions (as discussed earlier). The physical effect of these surface irregularities is that acoustic energy at the related frequencies gets scattered at many angles, with some higher frequencies further absorbed by frictional effects within the small cavities of surface features, contributing to the extant gallery acoustic that we have characterized as a "diffuse" sonic environment with reverberation times less than 1 second for most frequencies (Abel *et al.* 2008).

In order to compare the acoustic reflective and absorptive characteristics of extant and supposed ancient surface conditions, we are working with a reconstructed Chavín-style stone and earthen mortar wall that can be measured in its stone-surface state, clay-plastered and re-measured, resurfaced and re-measured, to replicate and capture the acoustic effects of several plausible ancient surface conditions, with its surface-dimensional variations photogrammetrically mapped. Our goal is to generate data that will elucidate details of surface material acoustics to use in com-

8 Spatial resonant modes or "room modes" can exist between any or all surfaces of an enclosed space, although the closest parallel surfaces tend to produce the strongest effects.

puter modeling applications, such as those proposed (Kolar *et al.* 2010) and in development by our team. Using results from the reconstructed wall measurements, we envision building an empirical testing platform that will accurately model the physical dynamical variations and enable simulations for psychoacoustic evaluation in order to understand the perceptual implications of the acoustic differences in construction materials and surface conditions.

Site-Contextualized Psychoacoustics

Questions regarding the implications of site acoustic and instrumental interactions for human perception have compelled the design and implementation of on-site psychoacoustic experimentation with human participants (doctoral dissertation research of Miriam Kolar). Psychoacoustics is an experimental science that examines the auditory perceptual and cognitive responses of human beings to sound. Systematic and controlled experimentation permits the evaluation of perceptual effects across a group of participants, providing conclusions more representative than those from the biased observations of a sole researcher or investigatory team. While established psychoacoustic principles can inform archaeoacoustic research, auditory perceptual experiments conducted within the Chavín galleries (Kolar 2012) test specific dynamics relevant to the site context. For example, a person's aural understanding of his or her physical location in a space and with respect to others underlies communication dynamics, which are fundamental for ceremonial contexts, and of heightened importance for the premise of "Chavín as a tradition-based convincing system" (Rick 2004). This research will be detailed in forthcoming publications, and has implications for the sounding oracle hypothesis discussed later. Future psychoacoustic research might consider the site-contextualized perceptual effects of low-frequency and infrasound energy, which have been shown in laboratory studies to induce physiological and psychological responses (Schust 2004). Not only are low-frequency resonances prevalent within the Chavín gallery system, but low-frequency phenomena are produced, for example, through the interaction of multiple sound sources whose fundamental frequencies differ slightly. This acoustic wave interference behavior, called "beating," is a linear amplitude variation (e.g., Hartmann 1998) that implies a variety of psychoacoustic and physiological effects when considered in contexts of Chavín architecture (interview between Kolar and Cook 2011).[9] Ceremonial participants in ancient site ritual would be psychologically primed for heightened sensitivity to environmental stimuli, and further through the use of psychoactive plant substances (conference paper given by Lubman and Rick 2002; Kolar 2012. The auditory perceptual implications of psychotropic experience at Chavín is an important and methodologically challenging topic that has yet to be probed in academic research. However, findings from on-site auditory perceptual experiments already demonstrate that applied psychoacoustic research can be useful in relating archaeoacoustic results with human experience.

The "Great Voice" of Chavín: A Sounding Oracle

Historical repute as an oracle center (Lumbreras *et al.* 1976; Diessl 2004; Lumbreras 2007) situates Chavín as a devotional and utilitarian fulcrum. The first publication exploring acoustics at Chavín discusses the role of a possible sounding oracle: "A thundering, sounding building is a lot more impressive for pilgrims than a silent 'oracle'; additionally, the sound's source, hidden below the building, only known by the priests or the initiates, is part of the 'mystery' necessary for a liturgy with fierce and grumbling gods. The 'talking god' or 'roarer' is an excellent complement for the religious (and economic) success of idols such as the 'Lanzón' of Chavín. The prestige of the site could be tied to the precision of the 'oracles' (for astronomy) and to the liturgical paraphernalia of the temple." (Lumbreras *et al.* 1976: 9 [transl. Kolar]).[10]

9 https://ccrma.stanford.edu/groups/chavin/interview_prc.html.

10 "Un edifico tronante, sonoro, es mucho más impresionante para los peregrinos que un 'oráculo' silencioso; además, la causa del sonido, escondido bajo el edificio, sólo conocida por los sacerdotes o los iniciados, es parte del 'misterio' necesario para una liturgía con dioses feroces y gruñentes. El 'dios hablador' o 'rugiente' es un excelente complemento para el éxito religioso (y económico) de ídolos como el 'Lanzón' de Chavín. El prestigio del sitio podría estar ligado a la precisión de los 'oráculos' (por astronomía) y a la parafernalia litúrgica del templo."

Such premises trigger a search for acoustic evidence that can support the idea of ancient Chavín as an oracle site, a place in which specialized and perhaps codified information transmission would have played a primary role, enabled and enhanced by the use of sound. Chavín, in the age of modern tourism, touts its sanctum, the "Gallery of the Lanzón Idol," whose extant floorplan consists of two perpendicular corridors on one level – though an upper level and additional ducts existed in prior construction – with its long central corridor narrowing slightly toward the visitor's objective. The relief-carved granite monolith (Fig. 1) is preserved in a sunken cruciform room whose architecture changed several times during the site's construction (Kembel 2001). The Lanzón is now separated from visitors and the gallery's central corridor by a glass door (which must be opened and acoustically damped during acoustic measurement sessions). Beyond question, this icon holds symbolic value in its decoration, surrounding architecture, and location within the complex, meanings obscured from our present-day vantage. However, vital physical clues converge to suggest, from an acoustic perspective, a new interpretation that offers a functional hypothesis. Historical references to a Chavín oracle (see, for example, Paulsen 1974; Lumbreras *et al.* 1976; Burger 1988; Moore 1996; Lumbreras 2007) justify mechanical examination: how might this "Great Image" invoke a "Great Voice"?

The physical orientation and setting of the 4.5 m-tall monolith merit attention: its engraved anthro-zoomorphic mouth is centered on the approximately 12 m-long interior corridor that leads eastward, toward the exterior Circular Plaza. At

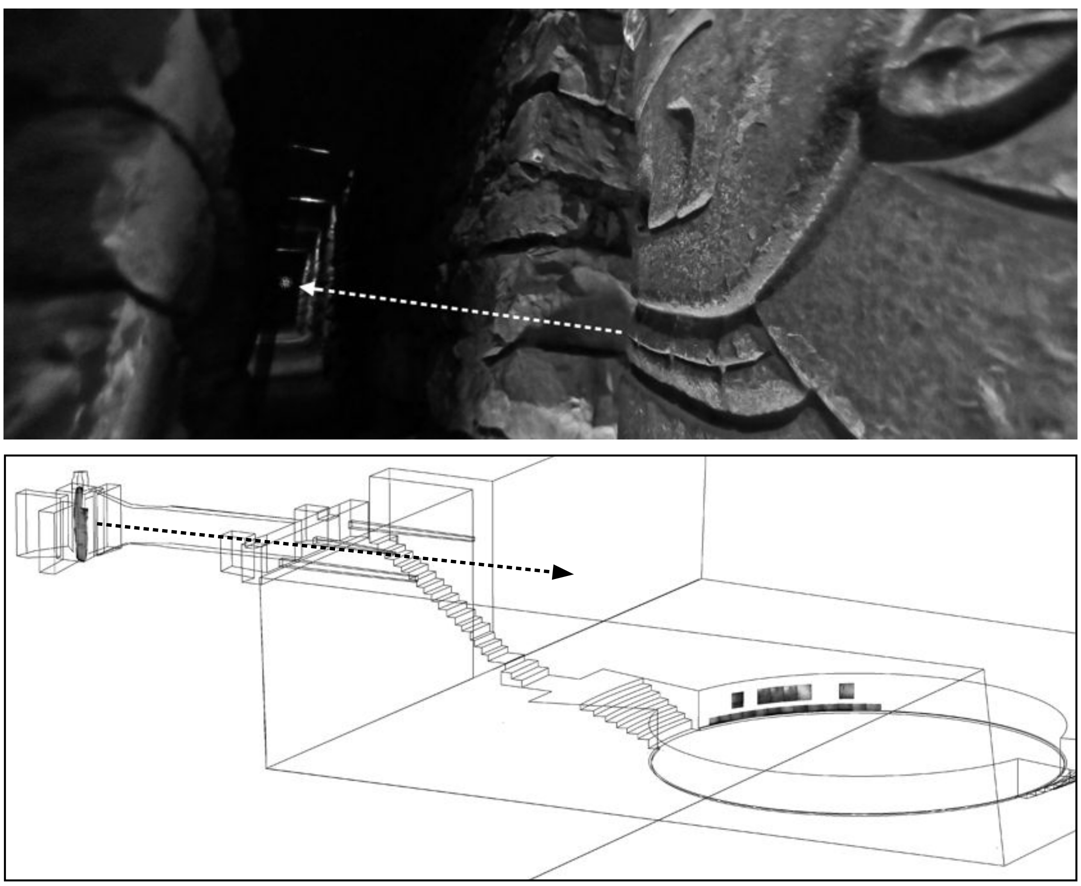

Fig. 12 Architectural alignment or "line-of-speech" between the Lanzón monolith and Circular Plaza: (a) Graphically simulated light entry marks the interior opening of the central duct aligned with the engraved mouth of the Lanzón, marked with an arrow; (b) Extant structures and estimated ancient plaza walls show architectural relationships between Lanzón Gallery and Circular Plaza. Simulation (a) by Miriam Kolar. Reconstruction (b) by José Luis Cruzado Coronel.

the corridor's intersection with the gallery's eastern wall, a central duct of approximately 4.5 m length continues this alignment, at the level of the icon's carved mouth, directly connecting the gallery interior with the plaza's principal staircase outside the gallery. This alignment constitutes a line-of-sight, and perhaps symbolically, a "line-of-speech," between the mouth of the "Great Image" and the exterior world of the plaza (Fig. 12). The shape of this central duct is notable: while other Chavín ventilation shafts narrow slightly toward their exterior openings, the tapering of this central duct is exceptional. Its interior opening measures about 33 cm wide by 40 cm high, and its exterior opening is 12 cm wide by 8.5 cm high, an aperture smaller by a factor of about 3.6:1, an extreme narrowing of the duct as it reaches the plaza outside. Because the duct terminates on the staircase, an architectural element not altered by modern reconstruction (verified by Kolar with the excavating archaeologist, Lumbreras, 9 September 2011), it is likely that ancient architecture is preserved here, although exterior constructions may have enclosed part of the staircase.[11] Two flanking ducts, originating at interior locations near both ends of the Lanzón Gallery's eastern corridor, run parallel with this central duct, but exit at longer distances, about 7 m on the partially intact walls at either side of the staircase. In a minimal reconstruction of the ancient plaza surroundings, based on extant wall fragments and data from Kembel (2001: 293-295) and Lumbreras (2007: 150, 170), these side ducts would terminate several meters farther east, at almost double the distance of the central duct, on high walls that no longer exist. The extant, incomplete terminations of the side ducts are shown within estimated walls in a reconstruction by José Luis Cruzado Coronel (Fig. 12b).

Measurement and Analysis of the Lanzón Duct Acoustics

Acoustic measurements were made to understand how these three ducts transmit and filter sound. With an ESS test signal[12] reproduced from a single-driver loudspeaker (Meyer MM-4XP) positioned at their interior openings, acoustic energy traveling through the ducts toward the Circular Plaza was measured by Kolar, recorded via four omnidirectional microphones (Countryman B6) located at various positions within the ducts, near both ends. Quantitative results are shown here as acoustic frequency response diagrams (Fig. 13); note that sound frequency (x-axes) is shown on a logarithmic scale to represent perceptual scaling; amplitude (y-axes) is shown in decibels (dB). Each graphed line corresponds to a measured impulse response from one of the four microphones aligning the ducts; three consecutive tests are plotted, with near-perfect overlap demonstrating the repeatability of this method. Analyses show that all three ducts substantially filter sound: frequencies in the range of the Chavín *pututu* sounding tones are emphasized relative to other frequencies (noted in Fig. 13, boxed areas in top 3 graphs). This effect, which can be compared to an "equalization" or "EQ" boost in audio equipment or software processing, accentuates sound frequencies in the range of 100-400 Hz by more than 10-20 dB above the rest of the audible spectrum, a proportion that can be understood perceptually as one to two doublings of amplitude (to a listener, 10 dB is twice as loud). Thus, the amplitude of these selected sound frequencies is preserved, and higher frequencies are suppressed, over the course of sound transmission from inside the Lanzón Gallery to the exterior ends of the ducts at the Circular Plaza. While the measured sounding frequencies of the Chavín *pututus* range from 272-340 Hz, player hand insertion in the instrument bell readily lowers these tones such that the manually shifted frequencies coincide with the lower range of the resonant peak of the ducts. This instrumental intonation technique allows a player to match the sounding tone of a shell horn with an architectural resonance, such as these measured in the Lanzón ducts, for maximum sonic reinforcement. These ducts could have been amplifiers for the Chavín *pututus*.

Would the ducts have similarly transmitted sounds from sources other than *Strombus* horns?

11 Several views exist among archaeologists regarding the ancient exterior of the Circular Plaza. Lumbreras and Kembel both argue that the principle staircase was at least partially enclosed (pers. com. 2012).

12 Exponential sinusoidal sweep (ESS) measurements are discussed previously, and detailed in Farina (2000, 2007).

Many sound sources, including *pututus* and the human vocal mechanism, can produce frequencies in the range boosted by the ducts. However, the human voice, like typical natural sounds, is specifically characterized and defined by its high-frequency components, sound energy in a range that is not transmitted by the ducts. Notably, the central duct transmits one particular high-frequency component that helps define the Chavín *pututus*' sound quality. While all three ducts selectively pass frequencies in the lower-frequency sounding range of the Chavín *pututus*, only the central duct's physical form corresponds to an acoustic difference that accentuates articulatory tones from the higher harmonics produced by these *pututus* (noted in Fig. 13 , boxed area in lower graph). In our Chavín *Strombus* measurement analyses, we documented strong spectral resonance for the higher harmonics of the instruments, noting peaks at the second harmonic (H2), from 575-706 Hz, and at the third harmonic (H3), from 826-1046 Hz, in the 19 site-excavated shell horns. At the exterior openings of all three ducts, the *pututus*' H2 frequencies are suppressed by about 40 dB relative to the H2 level recorded at their interior openings, but while the side ducts further suppress the H3 frequencies by 45-55 dB, the central duct gives another resonance peak at H3 of about 20 dB in the region of 800-900 Hz, equal to a suppression of only about 20 dB between interior and exterior. H3 frequencies, important to the articulation and character of the shell horns, are transmitted through the central duct. Because it emphasizes this important articulatory frequency component of the sound of the Chavín *pututus*, the central duct realistically transmits the sound of *Strombus* shell horns played from interior to exterior, projecting it with "presence" and realism not matched by the side ducts.[13] This difference between center and side duct filtering can be seen in comparing the frequency responses ("equalization curves") recorded at the exterior openings of each duct (Fig. 13, lower graph). At their exterior openings, all the ducts boost frequencies in the range of the *pututu* sounding tones (H1), but only the central duct (thickest line) boosts frequencies in the shell horns' third harmonic (H3) articulatory range (indicated by boxed area). In summary, all three ducts transmit and emphasize acoustic frequencies in the range of the measured sounding tones and readily modulated lower tones produced by the site-excavated *pututus*, and the central duct further emphasizes the articulatory range of the shell horns, accentuating their sound compared to the side ducts. The architectural acoustic filtering properties of these three ducts constitute a specialized sound transmission system.

Acoustic Features and Psychoacoustic Effects in the Circular Plaza

Acoustic measurements demonstrate that the central duct connecting the Lanzón Gallery with the Circular Plaza selectively filters, thus emphasizes, the sound of the Chavín *pututus*. How does this acoustic design element function with respect to the greater setting where its sound is dispersed? The floor of the approximately 20 m-diameter Circular Plaza is located below surrounding terraces and building facades; "sunken" to the extent that environmental sounds – notably, the roar of the two adjoining rivers – practically disappear, and site architecture dominates one's vision on all sides. No other exterior location in the extant monumental complex so silences the outside environment. A quiet environment would be important in commanding listener attention for ritual focus, plausibly heightened in the Circular Plaza as opposed to the larger Square Plaza, in part due to the improvement in background noise reduction.[14] Acoustic focussing effects are known to result from concave structures and circular enclosures, which would further contribute to an enhanced auditory environment in the ancient plaza, especially in combination with strong sound reflections from the surrounding high walls. Similar to other exterior spaces in the present-day site, the Circular Plaza area has been degraded and modified by post-Chavín constructions, with incomplete walls, vegetation, rubble, and newer architecture (as seen in Fig. 10) appreciably affecting acoustic dynamics. For this reason, its ancient acoustics cannot be accurately understood through making observational tests, so computational acoustic modeling is required to reconstruct and simulate dynamics of the pla-

13 For a discussion of spectral peaks and articulation, see Cook (1999a, 1999b).

14 See Beristain (2010) for a discussion of how noise levels affect speech reception in Mesoamerican sites.

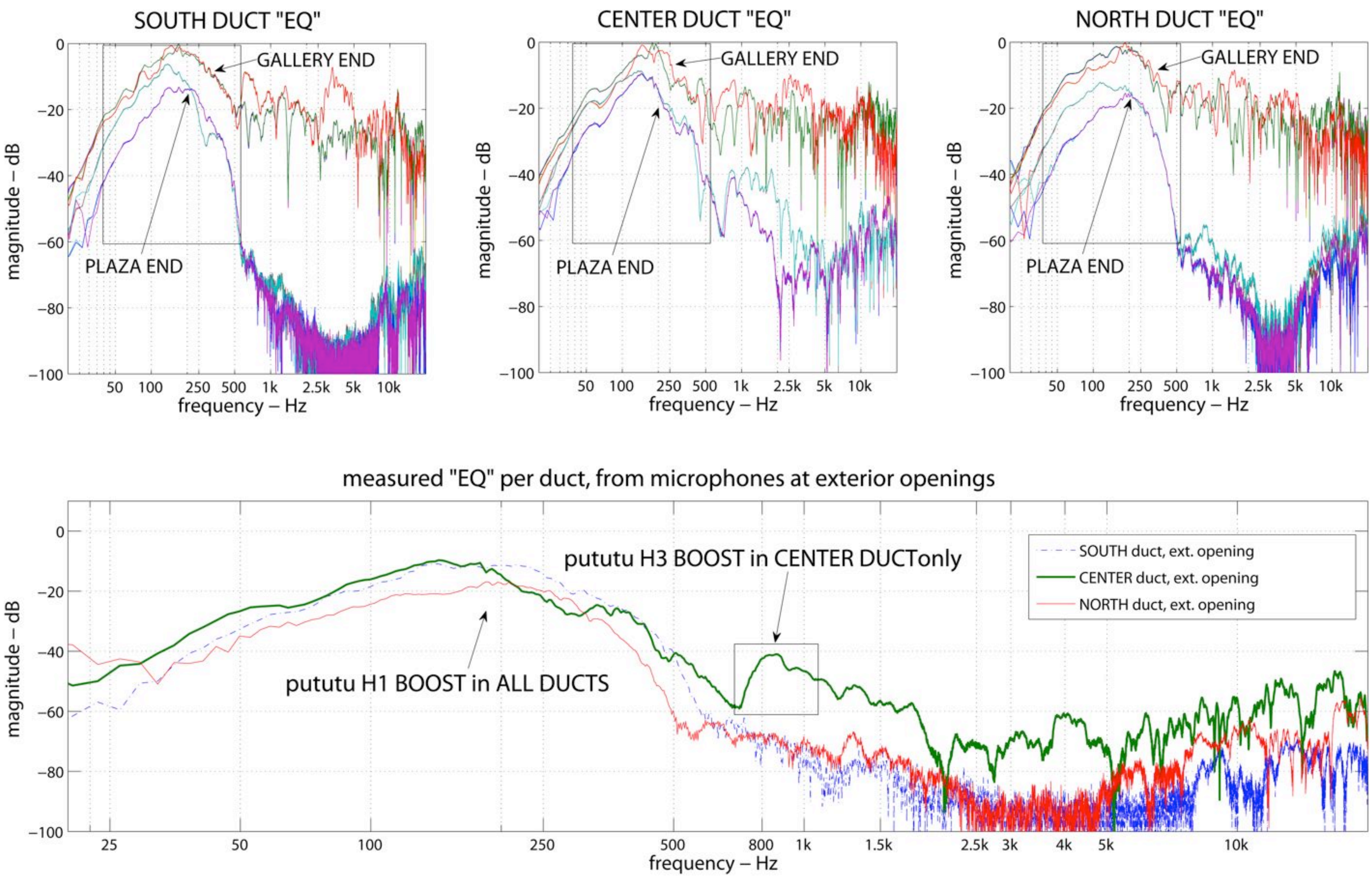

Fig. 13 Measured acoustic frequency response magnitudes ("EQ-curves") for the 3 ducts connecting Chavín's Lanzón Gallery and Circular Plaza. The top graphs show filtering at all measured locations within each duct, for three tests per duct (overlapping data confirms repeatability). The lower graph compares equalization at the exterior openings of the three ducts: the central duct emphasizes the pututus' 3rd harmonic (boxed area). Diagram by Miriam Kolar and Jonathan Abel.

za's ancient sound environment. Such research will be necessary to explore our hypotheses regarding acoustic transmission and filtering in the Lanzón gallery-duct-plaza network, and to test the perceptual results for listeners, especially to compare several reconstruction possibilities. However, given data from extant measurements, we anticipate certain acoustic effects and auditory implications.

The following measurement-based estimates for ancient acoustic features derive from data analyses and our projections of established acoustic principles. The acoustic measurements discussed earlier provide data for the side ducts in their extant condition. If the side ducts were longer, we expect that sound amplitude at their exterior wall openings would be further decreased relative to the central duct (whose extant length terminates at an assumed ancient structure). However, the exterior-to-interior aperture difference of about 1.6:1 for the side ducts, versus 3.6:1 for the central duct, could boost some frequencies in the exterior response of the flanking ducts. Abel (pers. com.) has suggested that these three ducts could have had an ancient function analogous to a modern multi-channel loudspeaker system, to project sound from inside the gallery out to the plaza, with exterior listeners' perceptual focus forced by selective equalization. Panning effects (the multiple-loudspeaker simulation that sound moves from one location to another) could be created by manipulating the delivery of interior sound sources. For example, the directionality of the *Strombus* horns could be leveraged in combination with the architectural acoustic filtering dynamic of the ducts. Our current analysis shows that sounds produced in the gallery, near the duct openings, containing primarily the filtered frequencies (such as *pututu* tones), pass through the central duct with minimal distortion. In contrast, sounds that contain not only the preferential frequencies but are characterized by higher frequencies (such as human speech), would not be transmitted in their entirety due to the filtering effects of these ducts. Such sounds, produced at the interior, would be unnaturally transformed or distorted after passing through the ducts. The ducts function as mechanical filters that may, in fact, transform all sounds that pass through them to seem more like *pututu* tones. Thus, we posit that these ducts may have been specifically constructed as conduits for *Strombus* horn sound transmission, not excluding the likelihood of their simultaneous functionality as air and light conduits. Computational acoustic modeling will be used to create auralizations of these scenarios, to be evaluated informally by researchers, and systematically tested in psychoacoustic experiments with unbiased participants in order to better understand the auditory implications.

For a listener located within the ancient Circular Plaza, we propose that two complementary perceptual effects would contribute to centralized auditory focus in the ritual sound environment. Sound created inside the Lanzón Gallery by a person playing a *pututu*, speaking, chanting, or singing, would be manifested for an outside listener as a *pututu*-like voice emanating centrally, from deep within the building, as if from the place of the mouth of the monolith or oracle (and actually aligned with it). The central duct's shape facilitates this heightened projection of reality, leveraging the so-called "precedence effect" (see, for example, Litovsky *et al.* 1997, 1999; Blauert 1997) that causes a listener to perceive the source of a sound from the direction of its first arriving acoustic wavefront: the central duct is the shortest transmission path for sound produced inside the gallery, on its central axis, to enter the outside world (as illustrated in Fig. 14). This duct's filtering structure further emphasizes selected frequencies in the third harmonic articulatory range of the Chavín *pututus* so that shell horn sounds arrive with greater definition at the exterior than any incidental dispersed sound from inside the gallery that arrives later, at lower amplitude, via the two parallel side ducts. The result, due to the central duct's acoustic path length and its equalization, is that sound produced inside the Lanzón gallery impresses an outside listener most prominently from the direction and location of the central duct's opening on the staircase.[15] Perceptually, sound would seem to emerge from the location of the Lanzón, the "Great Voice" of Chavín, its proposed oracle. In contrast, sound produced near the interior openings of the side ducts would arrive with a different timbre, or quality, at the exterior, compared

15 An enclosed staircase could also maintain this effect by functioning as a "reverberation chamber," additionally enhancing *pututu* sounds transmitted by the duct.

to sound transmitted through the central duct. To consider an alternate scenario: *pututus* played simultaneously at the interior openings of the side ducts would also produce the perceptual effect of a centered source. This effect is similar to that in a modern stereo loudspeaker system: when equal sounds are simultaneously reproduced in both left and right channels, a solitary centralized "image" results.[16] Thus, the side duct acoustics alone could force central sonic focus, aligning listener attention with the unseen Lanzón. Whether or not visitors were aware of the monolith's position, the alignment provides a direct connection for the cult members serving as ritual facilitators. For visitors seeking cult initiation, the acoustic connection and physical alignment of the duct between the monolith's mouth and Circular Plaza could have served as a rhetorical axis in the progression of ceremony between public exterior areas and increasingly private interior spaces. Following ideas posed by Kembel and Rick, select ceremonial participants may have eventually visited the interior Lanzón Gallery to more directly interact with the monolith, as part of a ritual initiation process that moved from external public spaces to private interior areas (Rick 2004; Kembel and Rick 2004).

Planned future research will model and test these proposed acoustic dynamics and perceptual effects, and should illuminate other possibilities, such as those related to sound reflections around the principle staircase. Any physical connection between the central duct and the so-called "acoustic canal" (see Lumbreras 1974, 1976) that runs below the same staircase would enable acoustic coupling that should be studied and simulated computationally, in order to understand the combined dynamics of these empirically demonstrated acoustic systems.

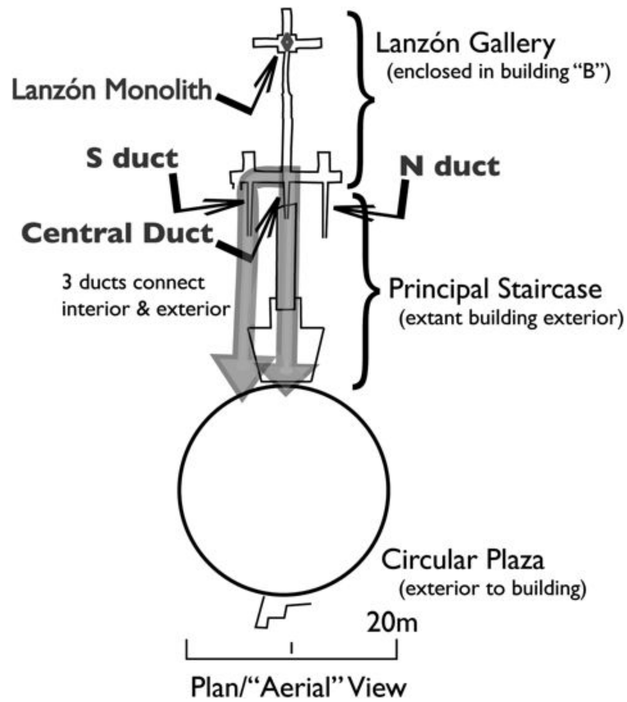

Fig. 14 Schematic for sound transmission between the interior Lanzón Gallery and exterior Circular Plaza. Scale map (plan/"aerial" view) shows architectural relationships, as well as the relative lengths of two sound transmission paths (arrows) from a central source in the gallery, through its ducts, out to the plaza. Diagram by Miriam Kolar, 2012 (adapted from Kembel 2001).

Ancient Performance Settings for the Chavín Pututus

Empirical research methods have given us material data regarding the architectural acoustic dynamics between the Lanzón Gallery and Circular Plaza, a ceremonial nucleus in the Chavín complex. Our systematic analysis illuminates a structural acoustic connection between the proposed oracle and exterior ceremonial locus that can be manipulated using site-excavated instruments. Acoustic data support the interpretation of the physical narrowing of the gallery's central duct as a construction technique that "tunes" its equalization to emphasize the sound of the site-excavated *Strombus* shell horns and exclude other qualities of sound. This structure, aligned with the mouth of the site's "Great Image," functions as an architectural acoustic filter to project the sounding tones and articulatory harmonics of the Chavín *pututus* from inside the Lanzón Gal-

16 For a centrally located listener; if the listener is closer to one loudspeaker, the image may be shifted in that direction; however, in this case, the surrounding concave walls would refocus sound energy back to the center.

Fig. 15 Fossil marine shell inlay in the floor of the Circular Plaza, located north of its principal staircase, near the pututu-player facing-stones shown in Fig. 3d. Photo by Miriam Kolar.

lery out to the Circular Plaza. This finding augments other evidence that the prominently represented Chavín *pututus* were specifically associated with the Circular Plaza and its immediate surroundings.

A review of material evidence relates the Circular Plaza with marine shells. Inlaid in its floor are two marine snail fossils (one shown in Fig. 15). The gallery to its north, named *Ofrendas* (meaning "offerings" in Spanish), contained a notable concentration of *Spondylus* shell fragments (Lumbreras 1993, 2007; Rick 2008), while the adjoining southern gallery, which was descriptively named *Caracolas* for its *Strombus* fragment content, was later excavated to uncover the Chavín *pututus*. As detailed in Fig. 3, the plaza's relief-carved facing-stones depict *pututu* players (locations noted in Fig. 10 and in Fig. 12b). "The sequence of facing-stones on the NW – keeping in mind that the first five are not known – starts with an anthropomorphic character looking forward, who is followed by two players of 'pututus' (shell trumpets or horns) and a third character, who seems to be blowing on or presenting another object that has rays or spikes, like those of the *Spondylus*." (Lumbreras 2007: 177 [transl. Kolar]).[17]

Whereas the Circular Plaza seems a probable ceremonial location for ritual use of the Chavín *pututus* given the confluence of evidence, comparative studies of instrumental and interior acoustics demonstrate that these shell horns produce audible and observed physiological effects in their interaction with gallery resonances. Strong blasts, smooth drones, and short, percussive articulations perceptibly engage interior acoustic features, and propagate throughout the site's internal architecture. In experiments with *Strombus galeatus* replica horns, Rick has shown that *pututus* can be used as megaphones to simulate feline roars, a sound effect suggested by the prominence of feline imagery at the site. We have not identified specific shell-horn articulations that are arguably more or less effective with interior architectural acoustics, and posit that all may induce perceptual effects that could be important to the ritual context. As discussed earlier, the playing orientation of *Strombus* shell horns can be varied to produce effects related to the directional acoustic radiation pattern of these instruments, and knowledge of such could be employed to manipulate listeners' perception of sound source location, additionally supported in our recent psychoacoustic research (Kolar 2012). Although site iconography does not specifically link gallery spaces with *pututu* performance, the fragmented (now re-assembled), orb-shaped *Ofrendas* ceramic known as Sp.487 (Lumbreras 2007: 496-497) might be interpreted to depict *Strombus* and *Spondylus* moving through enclosed passages of the complex (Fig. 16).

Concluding Proposition: Chavín *Pututu* Masters as Oracular Intermediaries

Our integrative archaeoacoustic survey at Chavín brings together multi-faceted forms of evidence to posit characteristics and auditory implications of the acoustic environments that animated ancient ceremony. In these investigations, we have expanded on ideas proposed by Lumbreras, González, and Lietaer (1976), through acoustic

17 "La secuencia de las lápidas del NW – recordando que no se conocen las cinco primeras – se inicia con un personaje antropomorfo visto de frente, que está seguido por dos bocineros de "pututu" (caracola trompetera o bocina) y un tercer personaje, que al parecer sopla o presenta otro objeto que tiene rayos o espículas, como las del *Spondylus*."

Fig. 16 Two views of the Ofrendas ceramic, Sp.487 (56627/MAAUNMSM-199/INC-03/L.487), discovered in cell 1 of the Ofrendas Gallery by Lumbreras. Pututus and mullus are separated by structures similar to gallery forms. Photos: Miriam Kolar, from the collection of the Museo de Arqueología y Antropología de la Universidad Nacional Mayor de San

measurement and analysis of sound transmission within the Chavín gallery system and its duct architecture, and we introduce interpretations. Comparative study of the functional dynamics of the Chavín *pututus* with site architectural and environmental acoustics gives new data regarding the potential for human manipulation of sound using these instruments in site galleries, exterior spaces, and with surrounding landforms. We have shown how selective sound transmission between the Lanzón monolith and the Circular Plaza was made possible by an architectural acoustic filter system, plausibly constructed to project the sound of the Chavín *pututus* and obscure other sounds. Ongoing psychoacoustic research contextualizes human auditory experimentation in Chavín galleries, systematically testing hypotheses regarding the auditory perceptual effects of architectural and instrumental acoustics. These integrated research endeavors are expanding our understanding of the sound environment experienced by ritual participants in ancient Chavín.

Where do these archaeoacoustic research findings intersect with the development of archaeological hypotheses and insights about Chavín ritual? Our research gives weight to the premise of Chavín as a place where specialist technicians collaborated to create a multi-sensory ritual environment. The Chavín *pututus*, long-used marine shell horns, are depicted across site iconography and in focal locations at the complex. These highly visible instruments are not easily mastered devices, yet with practice, they can be manipulated to produce a plethora of sounds, from nearly pure tones to noisy feline roars. Acoustically, these shell horns exploit site acoustics, and are simultaneously amplified and projected by site architectural and environmental acoustic dynamics. Instrumentalists at Chavín would probably have been expert players, virtuosos renowned and elevated in status for their abilities. In Chavín ritual, such *pututu* masters may have been intermediaries with the oracle, and these same specialists could enact oracular voicings via their powerful instruments.

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