Virtual Archaeology Review, **14**(29): 1-13, 2023
https://doi.org/10.4995/var.2023.19315

Received: February 28, 2023
Accepted: June 14, 2023

MORE THAN WORDS: A STUDY ON THE VISIBILITY OF HAND GESTURES IN PUBLIC SPACES. CASE STUDIES OF FORUM ROMANUM AND MAYAN TIKAL

MÁS QUE PALABRAS: UN ESTUDIO SOBRE LA VISIBILIDAD DE LOS GESTOS CON LAS MANOS EN LOS ESPACIOS PÚBLICOS. ESTUDIO DE LOS CASOS DE FORO ROMANO Y TIKAL MAYA

Kamil Kopij[a,*], Kaja Głomb[b], Szymon Popławski[c]

[a] Institute of Archaeology, Jagiellonian University, 11 Gołębia St., 31-007 Kraków, Poland. k.kopij@uj.edu.pl

[b] Faculty of Management and Social Communication, Jagiellonian University, 4 Łojasiewicza St., 30-348 Kraków, Poland. kaja.glomb@uj.edu.pl

[c] Faculty of Architecture, Wrocław University of Science and Technology, 53/55 B. Prusa St., 50-317 Wrocław, Poland. szymon.poplawski@pwr.edu.pl

Highlights:

- This paper focuses on the results of an experiment that allowed the authors to determine the maximum distance over which gestures of different sizes (with fingers, palms, whole hand, or hands) are visible.
- The results determine the maximum audience for two case studies: rostra on the Late Republican Forum Romanum in Rome and Pyramid No 3 in Late-Classical Mayan Tikal.
- Despite the larger area in Tikal, the results reveal that more people (approximately 11757 and 15782) could see all the gestures in the Roman Forum due to its spatial geometry.

Abstract:

Hand gestures play an important role in human communication. Although the study of their repertoires and roles for past communities is a popular field of research, there has been no attempt so far to study their visibility during public events. The aim of this study was to determine the maximum number of people who could see hand gestures well enough to understand their meaning. Using gestures taken from ancient Roman rhetorical treatises, which we divided into three classes related to the detail of the gestures (fingers, hand, arm, or arms), we conducted a series of experiments to determine the maximum distance from which each class of gestures could be seen. We used the results, including regression analysis, to conduct visibility analyses for two case studies: one on the rostra on the Late Republican Forum Romanum in Rome; and the other on Pyramid No 3 in the centre of Late-Classical Mayan Tikal. We used the calculation of the areas where gestures were visible to estimate crowd sizes by drawing on crowd behaviour observation during contemporary public gatherings. They show not only how many people could have potentially seen the gestures, but also what percentage of the theoretically available space could have been occupied by people who had the potential to see them. According to the findings, only a little under half (44.8%) of the maximum possible audience were able to detect all types of gestures (various levels of detail) at the LR Roman Forum, while at Pyramid No 3 in Tikal, just a mere 16.7% were able to do so. We believe that the results presented and the methodology used can be applied to analyse any public space, regardless of place and time, thus providing a valuable tool to comprehend past public assemblies.

Keywords: Forum Romanum; hand gestures; non-verbal communication; public gatherings; Pyramid No 3 in Tikal; visibility analysis

Resumen:

Los gestos con las manos juegan un papel importante en la comunicación humana. Aunque el estudio de sus repertorios y roles en comunidades pasadas es un campo de investigación popular, hasta ahora no se ha intentado estudiar su visibilidad durante eventos públicos. El objetivo de este estudio fue determinar hallar el número máximo de personas que podían ver los gestos de las manos lo suficientemente bien como para comprender su significado. Usando gestos tomados de los antiguos tratados de retórica romana, que dividimos en tres clases relacionadas con el detalle de los gestos (dedos, mano, brazo o brazos), llevamos a cabo una serie de experimentos que para determinan determinar la distancia máxima desde la cual cada clase de gestos podría ser visto. Usamos los resultados, incluido el análisis de regresión, para realizar análisis de visibilidad en dos casos de estudio, : uno en la tribuna del Foro Romano republicano tardío en Roma y el otro en la Pirámide n.° 3 en el centro de Tikal maya del período Clásico tardío. Usamos el cálculo de las áreas donde los gestos

*Corresponding author: Kamil Kopij, k.kopij@uj.edu.pl

eran visibles para estimar el tamaño de la multitud a partir de las observaciones del comportamiento de las personas durante las reuniones públicas contemporáneas. Muestran Se muestran no solo cuántas personas se estima que podrían haber visto potencialmente los gestos, sino también qué porcentaje del espacio teóricamente disponible podría haber sido ocupado por personas que potencialmente los vieron. De acuerdo con los hallazgos, solo un poco menos de la mitad (44.8%) del máximo de audiencia posible pudo detectar todo tipo de gestos (varios niveles de detalle) en el Foro Romano LR, mientras; sin embargo, que en la Pirámide No 3 en Tikal, solo un exiguo 16,7% pudo hacerlo. Creemos que los resultados presentados y la metodología utilizada se pueden utilizar usar para analizar cualquier espacio público, independientemente del lugar y el tiempo, proporcionando una herramienta valiosa para comprender las asambleas públicas de tiempos pasados.

Palabras clave: Foro Romano; gestos con las manos; comunicación no verbal; reuniones públicas; Pirámide No 3 de Tikal; análisis de la visibilidad

1. Introduction

Hand gestures, both iconic and 'beat' gestures (McNeill & Levy, 1982), are among the most visible elements of non-verbal communication using the human body. They have therefore received copious attention from researchers, mainly psychologists and communication experts. It has been established that they do not just accompany speech, but in the case of iconic gestures, they carry additional semantic information that is lacking in the spoken word. Understanding the message of the speaker is therefore only possible by simultaneously comprehending what they say and correctly interpreting the gestures they make (McNeill, 1992, pp. 12–14). Hand gesture expression, although culturally and individually varied, is a universal form of non-verbal communication. The abundance of iconographic material from various historical periods and cultural circles containing hand gestures indicates that we have always "spoken with our hands" both on a daily basis and in the more ritualised forms of public gatherings and religious ceremonies. In recent decades, this topic has intrigued historians and archaeologists seeking to understand the meaning of gestures of representatives of ancient civilizations (cf. Aldrete, 1999; Bishop & Cartmill, 2021; Bremmer & Roodenburg, 1993; Cifarelli, 1998; Fox, 1995; Frye, 1972; Gardner 2022; Hudson & Henderson 2022; Jones, 2019; Kekes, 2021; Miller, 1981; Saunders, 1985; Wedde, 1999).

One of the best-studied cultural circles in this respect is the Greco-Roman world, not only because of the wealth of iconographic material but also written texts – including those that mention or even describe hand gestures (Cic. *Orat*; Cic.*Brut; Rhet.Her*; Quint. *Inst*. cf. Aldrete, 1999; Brilliant, 1963; Cairns, 2005; Corbeill, 2004; Freyburger, 1988; Giazzi, 2019; Graf, 1993; Hall, 2004; Keesling, 2005; Picard, 1936; Ricottilli, 2021; Salvo, 2015). One of the most well-known hand gestures derived from this culture is indicating the fate of a defeated gladiator. The image has become widespread in popular culture that a thumbs up signified mercy and a thumbs down signified the killing of an opponent, but the sources, in this case, are not precise enough to say with certainty what these gestures looked like. It may have been the other way around, i.e., a thumbs down may have meant encouragement for the victor to throw down his arms, and therefore grace for the defeated (Aldrete, 1999, 90-91). Balsdon (1969, 300), on the other hand, argued that a thumbs down (lat. *pollicem premere*) was a gesture of grace, whereas putting the thumb to the chest (lat. *pollicem vertere*) meant death.

The ancient Roman rhetor and teacher Marcus Fabius Quintilianus wrote of the importance of hand gestures as follows:

> *As for the hands, without which all action would be crippled and enfeebled, it is scarcely possible to describe the variety of their motions, since they are almost as expressive as words. For other portions of the body may help the speaker, whereas the hands may almost be said to speak. Do we not use them to demand, promise, summon, dismiss, threaten, supplicate, express aversion or fear, question or deny? Do we not employ them to indicate joy, sorrow, hesitation, confession, penitence, measure, quantity, number and time? Have they not power to excite and prohibit, to express approval, wonder or shame? Do they not take the place of adverbs and pronouns when we point at places and things? In fact, though the peoples and nations of the earth speak a multitude of tongues, they share in common the universal language of the hands.* (Quintilian, 1921-22: 11.3.85-87)[1]

Given that public gatherings and religious ceremonies could be and were attended by substantial numbers of people (judging by population estimates and the public space available), the question is whether all those gathered had a chance to see and recognize the gestures of the person leading the event. This topic is related to visibility analysis in archaeology more broadly, which has been a popular research direction in recent decades (an overview of the topic with further literature: Verhagen, 2018, pp. 18–19). However, the most popular tools, GIS-based methods, do not consider the maximum distance from which variously sized objects or body parts are

[1] Quintilian (1921-22). *The Institutio Oratoria of Quintilian*. Vol. IV, trans. H. E. Butler. New York: Putnam.

visible. The question of the visibility of objects of different sizes has already been raised in the literature, and a number of solutions have been proposed to modify GIS-based visibility analysis (cf. Bornaetxea & Marchesini, 2022; Fisher, 1994; Ogburn, 2006; Wheatley & Gillings, 2000). Cognitive neuroscience research suggests that the human silhouette is processed differently from ordinary inanimate objects, and this process resembles analysis of the face (Stekelenburg & de Gelder, 2004). This type of visual processing is qualitatively different from object processing, so the use of tools designed for this class is insufficient for our purposes. Thus, as hand gestures are quite easy to categorise by 'size', in our study we decided to conduct a series of experiments to determine the maximum distances over which different gestures are visible.

Our article aims to present the results of these experiments and, based on them, to start a discussion on gesture visibility and spatial analysis through simplified case studies considering only the maximum distances over which gestures are visible. In this article, we deliberately do not take into account numerous factors that can interfere with their visibility. We therefore present the basic model and methodological framework, believing that in the future these results can be expanded and made more specific for more culturally and context-oriented studies, i.e. also taking into account culturally specific factors to better simulate (past) social reality.

2. Maximum visibility experiments

2.1. Methods and procedure

The aim of our study was to determine the maximum visibility of rhetorical gestures with respect to their level of detail. We considered three classes of gestures: made with the fingers, made with the hand, and made with the whole arm (hand gesture + arm movement). In addition, to generalize our findings to other public spaces we wanted to investigate how a viewer's ability to recognize gestures gradually declines. To meet the objectives, we decided to conduct a field experiment inspired by analogous research from the field of cognitive psychology devoted to object recognition. The experiment took place on Wawelska Avenue, the longest avenue of the Jagiellonian University Campus (a plan with the location marked was added to Supplement 1). The rostrum was set up at the northeast end of the avenue, while the subjects were positioned on the central promenade, completely exposed and without natural shades. The experiment took place in the forenoon and early afternoon hours. The experiment did not take place on rainy or heavily cloudy days. For organizational reasons, we were unable to control the degree of sunlight, however, we tried to ensure relatively comparable experimental conditions.

2.1.1. Procedure

The procedure involved the simulation of rhetorical gestures by a person playing the role of a Roman speaker (‘mock speaker’). The subjects' task was to recognize from different distances the gestures shown by the speaker.

To increase the efficiency of the study, we decided to conduct the experiment in two steps. First, we divided the distance of interest into 25 m sections. At this stage, we wanted to identify a wide section (e.g., 50-75 m or 100-125 m, etc.) in which gesture recognition declines. Then, in the second stage, we aimed at increasing spatial resolution so that the diminishing of gesture recognition could be determined with greater accuracy. Problems with obtaining conclusive results made it necessary to carry out an additional third step for one class of gestures.

The procedure was inspired by the classic research of Hager and Ekman (1979), who examined the recognition of human facial expressions at a distance. However, as COVID-19 pandemic restrictions made large-group studies impossible, we conducted the experiment in small groups of up to six subjects over multiple sessions. During each session, subjects were asked to recognize a gesture presented by the mock speaker at each successive 'milestone' marking the sections (50 m, 75 m, 100 m, and so on). At each milestone, the mock speaker displayed one gesture from each gesture class. The presentation procedure itself was based on a contemporary analysis of the organisation of gestural action (Kendon, 2004, 111-113). Each gesture unit began in a position of relaxation (or a home position) of the articulator(s). The experimenter then informed the participants that the expression phase was about to begin. The nucleus of each gesture (stroke + post-stroke hold) was standardized for the purposes of the experiment and lasted approx. 3 s, which was communicated to the subjects just before the start of the display. This was followed by a phase of recovery and preparation for the next demonstration. The subjects were informed that the gestures presented at each milestone were randomly generated from a pool of five gestures from each class selected for the study. The gestures could be different at each milestone, or they could be repeated. Subjects were to select a recognized gesture on a response card presenting five gestures, one of which was correct (Supplement 2). The gestures were taken from ancient rhetorical treatises (Aldrete, 1999), although some had to be modified for the purposes of the experiment. The gestures presented at each milestone varied from session to session, allowing us to discover the actual decline in recognition of gestures as such, rather than the decline in recognition of an individual gesture.

Due to the COVID-19 pandemic and the resulting difficulties in recruiting volunteers, as well as unfavourable weather conditions, the experimental sessions were carried out over a period of several months.

2.1.2. Group

The respondents were recruited via social media. Adults with correct eyesight (no defect or vision corrected with glasses or contact lenses) could participate in the study. To reduce the risk of high variance in cognitive functioning, which could affect the results, we decided to include only adults younger than 40 years old.

2.1.3. Results

2.1.3.1. Primary analysis (maximum visibility)

Statistical hypotheses. As the main goal of the experiment was to capture the maximum visibility of the rhetorical gestures, in the data analysis we decided to refer to the theory of probability, and the assumption that we can consider a class of gestures recognized when their recognition significantly exceeds the threshold of randomness. Consequently, in the case of our procedure (selection of one out of five gestures), the failure to recognize a given gesture occurs when its recognition rate does not differ from 0.2 (or 20%). The recognition rate can be defined as the proportion of subjects who correctly chose the gesture that was presented by the mock speaker at a given milestone to those who selected wrong gesture. In a situation when the recognition rate does not exceed the randomness threshold, we concluded that the gesture was guessed rather than recognized (Głomb, 2020).

In addition, in the second step of our study, we assumed that we infer maximum gesture visibility when recognition of a given gesture did not exceed the randomness threshold at two consecutive milestones. This criterion is arbitrary and represents a compromise between an overly liberal approach – in which we infer the maximum visibility of a gesture based on the decline of its recognition at the milestone closest to the speaker regardless of whether it was later still recognized – and an overly rigorous approach. In the studies conducted during the pandemic, an attempt to indicate a milestone after which no further recognition is made could have jeopardized the completion of the study within the intended time frame, as it would require us to conduct several additional sessions.

2.1.3.2. Analysis

Step 1

In the first step, our goal was to determine the maximum distance of gesture recognition with a spatial resolution of approx. 25 m. Thus, we analysed the recognition rates of five milestones delimiting the area of the largest public space of interest, the Forum Romanum.

To determine whether the recognition rate of a given gesture differed from random, we decided to use the chi-square goodness-of-fit test. The purpose of the test was to compare the number of people who recognized the gesture with the number derived from the premise that an unrecognized gesture is one whose proportion of recognizers/non-recognizers resembles a random distribution (.20). Table 1 presents the recognition rates of three classes of gestures at a given milestone examined during the first step of the experiment (n=30) (Supplement 3).

Table 1: Recognition rates of three classes of gestures at a given milestone in Step 1.

		Milestone				
		25 m	*50 m*	*75 m*	*100 m*	*125 m*
Class	*Fingers*	.47	.47	.40	.23	.20
	Hand	.97	.83	.77	.60	.67
	Arm	.93	.93	.83	.83	.90

Already a basic analysis of the data indicates that for two classes of gestures – those made with the hand and those made with the arm – the results differ significantly from our assumed level of randomness (.20). Chi-square analysis confirmed that. Thus, we conclude that in these sections the gestures were correctly recognized. This means that it is necessary to collect additional data from milestones set further from the speaker to enable us to determine the maximum gesture visibility for these two classes.

As for the hand gestures, we used a chi-square test to verify the hypothesis. The results of the tests performed for each milestone, presented in Table 2, indicate that according to the adopted criteria, recognition fades between 75 and 100 m.

Table 2: Chi-square results testing the difference between the numbers obtained in the study and those expected when the gesture was randomly selected, performed for each milestone for finger gestures in Step 1.

	Milestone				
	25 m	*50 m*	*75 m*	*100 m*	*125 m*
Chi-square	13.333	13.333	7.500	.208	.000
df	1	1	1	1	1
p	.000	.000	.006	.648	1.000

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were randomly selected (not recognized). N=30.

In summary, our preliminary analysis showed that for highly detailed and subtle finger gestures, their visibility significantly decays between 75 and 100 m. Less detailed gestures made with the hand or whole arm are, however, effectively recognized across the adopted space. This implies that the next step requires: 1) increasing the spatial resolution of finger gestures analysis to determine the maximum visibility distance with greater accuracy; 2) collecting additional data to determine the maximum visibility of hand and arm gestures.

Step 2

Finger gestures

As shown in Table 3, our secondary analysis indicates that the visibility of finger gestures declines between 80 and 85 m. Although at longer distances some people still correctly identified the gestures presented by the speaker, according to our criteria, we consider these recognitions as random hits on the correct answer.

Table 3: Recognition rates (Rec.) of finger gestures with the results of chi-square tests for consecutive milestones in Step 2.

	Milestone				
	80 m	*85 m*	*90 m*	*95 m*	*100 m*
Rec.	.50	.21	.18	.13	.26
Chi-square	21.375	.026	.059	1.112	.947
df	1	1	1	1	1
p	.000	.871	.808	.292	.330

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were not recognized. N=38.

The data suggest that recognition gradually fades with distance. At each successive milestone, the recognition rate decreased. The exception is the milestone located at

100 m, where the recognition rate was higher than at previous milestones. This could be interpreted as an effect of chance, as it does not exceed the level of randomness. It is possible, however, that the random selection of gestures chosen for this milestone made the set of gestures easier to recognize.

Since, as will be described later, we were compelled to perform yet another series of experiments due to the difficulty in determining the maximum visibility of hand and arm gestures, we decided to perform an additional measurement of finger gestures visibility at closer distances. This was to help us to better determine the regression of visibility in public spaces. Table 4 presents the results of the additional measurements (Supplement 4).

Table 4: Additional recognition rates of finger gestures with the results of chi-square tests for consecutive milestones in Step 2.

	Milestone				
	55 m	*60 m*	*65 m*	*70 m*	*75 m*
Rec.	.47	.41	.51	.35	.51
Chi-square	23.338	14.294	30.593	7.456	30.593
df	1	1	1	1	1
p	<.001	<.001	<.001	.006	<.001

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were not recognized. N=51.

The results indicate that, as predicted, finger gestures are correctly recognized at closer milestones. Recognition rates range from .35 to .51, meaning that a maximum of about 50% of people can see what gesture the speaker is making from this section. This result may suggest that the visibility of gestures at this distance is not very high, while recognition may depend on the individual predisposition of the viewer or random events interfering with the perception of visual information.

Hand and arm gestures.

In the second stage of the study, we collected more data to determine the maximum visibility of hand and arm gestures. Tables 5 and 6 show the recognition rates and chi-square test results comparing our recognition rates with the randomness threshold.

Table 5: Recognition rate of hand gestures with the results of chi-square tests for consecutive milestones in Step 2.

	Milestone				
	150 m	*175 m*	*200 m*	*225 m*	*250 m*
Rec.	.41	.37	.41	.24	.35
Chi-square	14.294	9.490	14.294	.397	7.456
df	1	1	1	1	1
p	<.001	.002	<.001	.529	.006

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were not recognized. N=51.

The second phase of the study still did not yield a conclusion. In the case of hand gestures, the results suggest that recognition rates do not exceed the level of randomness at the milestone located at 225 m, although better recognition rates were recorded in the next section (250 m). As a result, we did not meet the requirements for at least two more milestones with unrecognized gestures. We concluded that the hand gestures are still recognized between 150 and 250 m, although we suspect that the recognition rate recorded at 225 m may possibly be a false positive stemming from the randomly simpler set of gestures drawn for this section.

Table 6: Recognition rate of arm gestures with the results of chi-square tests for consecutive milestones in Step 2.

	Milestone				
	150 m	*175 m*	*200 m*	*225 m*	*250 m*
Rec.	.80	.80	.83	.65	.57
Chi-square	116.255	116.255	123.926	63.706	43.314
df	1	1	1	1	1
p	<.001	<.001	<.001	<.001	<.001

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were not recognized. N=51.

Moreover, as shown in Table 6, we also failed to capture the maximum visibility of arm gestures. The subjects recognized that class of gestures very well, which leads us to believe that their visibility is as high as the visibility of the human silhouette. Performing additional field reconnaissance, we noted that when the gesture involves moving the arm away from the torso on any plane, the visibility of this type of gesture can exceed up to 500 m. Since the object of our interest is a much smaller space, we decided to conclude the study of this class of gestures by recognizing that in typical public spaces such as forums, squares, yards or theatres, these types of gestures are well-recognized.

Step 3

Our final step was to determine the maximum visibility of hand gestures. Suspecting that we might have previously had a false positive result at the 250 m milestone, we decided to modify the experiment slightly. We, therefore, started at 250 m, setting an additional five milestones at every 10 m. Table 7 presents the recognition rates for the experiment.

Table 7: Recognition rates of hand gestures with the results of chi-square tests for consecutive milestones in Step 3.

	Milestone					
	250 m	*260 m*	*270 m*	*280 m*	*290 m*	*300 m*
Rec.	.32	.23	.26	.39	.13	.23
Chi-square	2.991	.129	.653	6.782	.976	.129
df	1	1	1	1	1	1
p	.088	.719	.419	.009	.323	.719

Note: A p score below the accepted alpha level (.05) indicates that the results are significantly different from random, i.e., the gestures were correctly recognized. A p score above the accepted alpha level indicates that the gestures were not recognized. N=31.

In line with our suspicions, the experiment showed that random gesture selection is recorded at 250 m. Neither was the level of randomness exceeded at the milestones of 260 m, 270 m, 290 m, or 300 m. However, to determine whether gesture recognition occurs at 250 m, we decided to perform an additional chi-square test including all the data obtained at this milestone (n=81). The recognition rate was .34, while the results of the test indicate that at 250 m, subjects' responses exceeded the threshold of randomness (Chi-square (1,81) = 10.256, p = .001). Thus, consistent with the assumption that we infer maximum visibility based on a milestone after which two consecutive measurements suggest guessing, we concluded that hand gestures are visible at 250 m.

In this case, we consider a result recorded at 280 m as a random false positive. The high recognition rate could also have been the result of drawing gestures for this section that were easier to recognize. It is possible, however, that with an increased sample size, the rate at this milestone would turn out to be lower.

To sum up the primary analysis, we determined that the visibility of rhetorical gestures increases with the “size” of the gestures. Subtle finger gestures are relatively well-visible only to people standing close to the speaker. Their maximum visibility was determined at about 80 m, while between 25 to 80 m their recognition remains relatively constant (about 40-50%). The slightly larger hand gestures remain clearly visible up to 125 m. Their recognizability fades gradually, although this steady decline is disrupted by some higher recognition rates. When it comes to arm gestures, the study concludes that this class of gestures is almost completely visible and recognizable up to 200 m, as evidenced by recognition rates of over 80% at milestones located in this space. We believe that this class of gestures can be relatively clearly visible even 500 m from the speaker or more.

2.1.3.3. Secondary analysis (visibility regression)

The purpose of the secondary analysis was to determine the regression of rhetorical gesture visibility by class, and to establish a regression equation that would allow our findings to be generalized and used across a variety of spaces – both historical and contemporary.

For the analysis, we considered all the data collected at every milestone (including preliminary studies not described in the main section). An analysis of the scatterplots of our data suggests that they allow for a simple linear regression analysis to determine how the average recognition rate of rhetorical gestures decreases as distances increase. Figs. 1-3 show the relationships between these variables with respect to the class of gestures.

All regression analyses were performed by weighting the means for the milestones – the mean for meters was assigned a value of zero in the model. This type of transformation results in a clear interpretation of the regression equation, where the individual parameters have their empirical equivalents. For finger gestures the mean distance was 75 m; for hand gestures, 185 m; and for arm gestures, 125 m.

Finger gestures

A univariate regression analysis was performed in which the response variable was the recognition rate, and the explanatory variable was the distance from the speaker (milestone). The proposed regression model was found to fit the data well (F (1,11) = 8.127; p = .015). Based on the regression coefficients, distance is strongly and negatively related to recognition (beta = -.654, p =.015). Our constant for the regression equation is .361 – this gives us the recognition rate prediction for the average distance from the speaker. Therefore, the model assumes that at milestone 75 m, the recognition rate is .361. The regression coefficient for finger gesture recognition is .0033. Thus, the equation indicates that with every meter the recognition rate decreases by .0033 (.33%). Summarized, the regression equation is $y = .361 - .0033x$.

The model tested explains 42.8% of the variation in the dependent variable. It is, therefore, possible that gesture recognition is also affected by other factors, such as contextual clues, gesture distinctiveness, and individual differences in cognitive functioning.

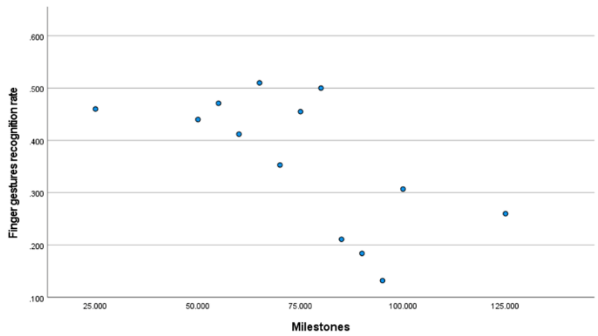

Figure 1: Scatterplot presenting the decline in finger gesture recognition at successive milestones.

Hand gestures

Again, a univariate regression analysis was performed with similar parameters. The proposed regression model was found to fit the data well F (1,13) = 96.710; p <.001. Based on the regression coefficients, distance is strongly and negatively related to recognition (beta = -.939, p <.001). The regression equation is $y = .456 - .0026x$.The equation indicates that with every meter the recognition rate decreases by .0026 (.26%), which is quite similar to finger gestures. The model explains 87.2% of the variation in the dependent variable; thus it can be concluded that distance is a very strong predictor of recognition in the case of hand gestures.

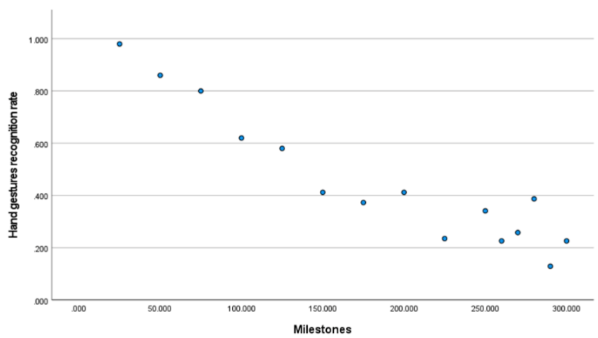

Figure 2: Scatterplot presenting the decline in hand gesture recognition at successive milestones.

Arm gestures

A third univariate regression analysis was performed for arm gesture recognition. The proposed regression model was found to fit the data well F (1,8) = 16.225; p = .004. Based on the regression coefficients, distance is again strongly and negatively related to recognition (beta = -.818, p = .004). The regression equation is $y = .819 - .0016x$ thus the equation indicates that with every meter the recognition rate decreases by .0016 (.16%). The tested model explains 67.0% of the variation in the dependent variable; thus, some other factors (e.g., individual, contextual) can predict the recognition rate of arm gestures as well.

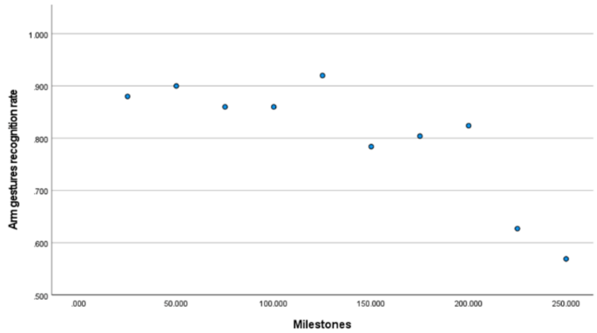

Figure 3: Scatterplot presenting the decline in arm gesture recognition at successive milestones.

Table 8: Summary of data analysis.

Class of gestures	*Max. visibility*	*Distance measured (M; min-max)*	*Regression equation*
Finger	80-85 m	75; 25-125	Y = .361 - .003 * X
Hand	250-260 m	185; 25-300	Y = .456 - .003 * X
Arm	Undetected	125; 25-250	Y = .819 - .001 * X

The results of our experimental study, summarized in Table 8, allow us to determine the maximum visibility of the gestures of a given class and to describe the gradual regression of visibility in space using a mathematical model. We also decided to assign to these quantitative parameters an additional qualitative value to delimit the visibility zones, from high to low. To do this, we decided to rely on a somewhat arbitrarily chosen analogy, which is the determination of correlation strength. Both the recognition rate and correlation take values from 0 to 1, so they are easy to compare. Thus, we decided to adopt a traditional model of describing the strength of the correlation, which considers that the interval 0-0.2 indicates no correlation. Analogically, in our study, we assumed that the lack of recognition is determined by the value of 0.2, indicating the random selection of gestures. Thus, we ultimately assume the following visibility zones for our gestures:

- 1) 1-0.9 [recognition rate] – complete/nearly complete visibility (C/NCV);
- 2) 0.9-0.7 – high visibility (HV);
- 3) 0.7-0.4 – average visibility (AV);
- 4) 0.4-0.2 – low visibility (LV).

These values were then compared with the regression equation obtained from the study, thus delimiting the zones in meters. Our assumption specified that the end of the low visibility zone would always be consistent with the experimental result specifying maximum visibility, even though the regression equation suggests that the zone is longer. The differences are due to the fact that regression analysis and chi-square test differ in terms of their null hypotheses, so their results are not identical.

Importantly, not for every gesture is it possible to indicate the zones of highest visibility. Although it seems that people standing in the immediate vicinity of the speaker in situ should be able to easily recognize the gesture, the method adopted by us has some limitations and does not allow us to state this with certainty.

Table 9: Visibility zone intervals for a given gesture class.

Class of gestures	*1* (1-0.9)	*2* (0.9-0.7)	*3* (0.7-0.4)	*4* (0.4-0.2)
Finger	nd	nd	nd-66	66.1-80
Hand	0-15	15.1-92	92.1-207	207.1-250
Arm	0-140	140.1-294	294.1-601	601.1-nd

Note: Ranges are given to the nearest meter.
nd – no detection.

3. Visibility analysis

3.1. Methods

Based on the results of our experiment, we analysed the visibility of gestures for two public spaces: Late Republican (LR) Forum Romanum (ca. 54 BCE) and the centre of the Mayan city of Tikal during the Late Classical period (ca. 550–830 CE). The former was chosen because the public speeches delivered during contiones – formal gatherings where Roman politicians addressed the people – were of great political importance at the time (Pina Polo, 1989). As hand gestures were also important for ancient Maya art and culture (Bishop & Cartmill, 2021; Ciura, 2015; Maitland Gardner, 2017; Miller, 1981), we decided to conduct an analysis of the Late Classical period Tikal to show that the results of our experiments – although based on Roman gestures – can be applied to analyse the visibility of gestures for different cultural backgrounds.

To conduct a visibility analysis of gestures, which determined on what part of the available space the gestures of the rhetor, or ritual leader could have been seen and recognized, we needed a virtual 3D reconstruction of the venue accounting for the topography of the site. We used reconstructions of the Forum Romanum built specifically for this study based on the current state of research (for details, see Supplements 5 and Supplementary References) and a reconstruction of the centre of Tikal found online[2]. The analyses were performed in ArcGIS Pro 2.9 using the Viewshed function in Exploratory 3D Analysis.

[2] https://3dwarehouse.sketchup.com/model/98b3ce54-3400-496e-ac95-df531e7033ef/Tikal-Central-plaza-palace-Temples?

Each study consists of two superimposed analyses for points differing in height by 0.6 m. This reflects the fact that gestures can be shown at various heights, from abdominal height to head height and even slightly beyond. For the analysis of the Forum Romanum, we used the heights of analysed points of 1.15 m and 1.75 m from the level of the speaking platform. We have adopted this range of heights based on estimates of the average height of male inhabitants of Italy during the Roman period, which is 1.683 m (Kron, 2005, pp. 72–74, Table 1). For the Tikal analysis, we used the analysis of points located at 1.05 m and 1.65 m from the level of the structure on which the person showing the gesture was standing, based on estimates of the heights of Mayan men of the Classical period, indicating an average of 1.599 m (Malina et al., 1983, pp. 446, Table 6). To ensure maximum realism of the analyses, the pavement, and other places of the Roman Forum where spectators could stand were raised by 1.50 m relative to reality (without raising the level of the speaking platform at the same time) so that the results of the analysis corresponded to the eye height of the gathered Romans. In the case of Tikal, the surface of the plaza was raised by 1.45 m for the same reasons.

In our analyses, we assumed that the gestures were visible enough to be recognized from an angle of 75º (especially as the speaker/ritual leader may have rotated his body to maximize his exposure to the audience), giving us a total horizontal viewshed angle of 150º (cf. Supplement 6).

3.2. Results

We first determined the maximum available space for the venues, which included all land not occupied by buildings. For the LR Forum Romanum, this was approx. 12500 m^2, and for Tikal, approx. 27500 m^2.

The second step of the analysis was to examine the visibility of the first class of gestures. In the experiments, we determined their visibility threshold to be between 80 and 85 m. For simplicity, we assumed that the visibility threshold was 83 m from the speaker. For the LR Forum Romanum and the speaker standing on top of the rostra (the speaking platform), the maximum area where the participants of contiones could stand and see the gestures is 5600.94 m^2 (Fig. 4).

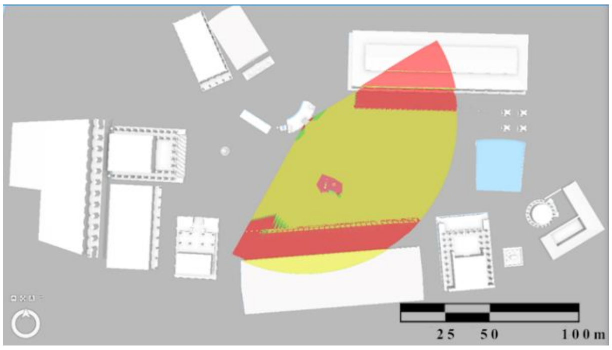

Figure 4: Results of finger gesture visibility analysis of the LR Forum Romanum (Yellow for the area where the gestures are visible; red for the area where gestures are nonvisible; green for the area where only the gestures made at the height of the head are visible).

For the plaza in front of Pyramid No 3 in Tikal, the area of available space where attendees could see the gestures of the ritual leader located on the upper terrace of the pyramid is 4583.98 m^2 (Fig. 5).

Figure 5: Results of finger gesture visibility analysis for Tikal. (Colour code as for Figs. 4)

The third step was to study the visibility of the first class of gestures using the results of visibility regression analysis. In this case, we have two levels of visibility: AV (0.7-0.4) and LV (0.4-0.2), which correspond to the ranges 0-66 and 66.1-83 m from the speaker. For the LR Forum Romanum, the area of the AV level is 4579.99 m^2 and the area of the LV is 1020.95 m^2 (Fig. 6).

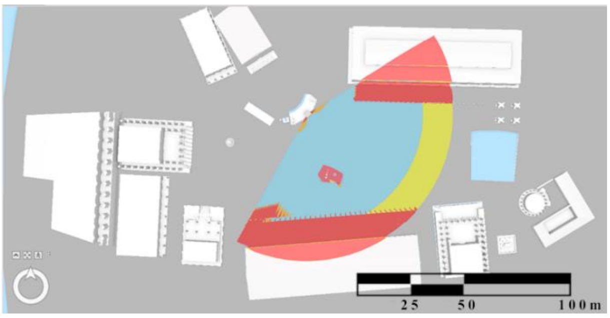

Figure 6: Results of the first class of gesture visibility analysis for the LR Forum Romanum with regression (blue for AV zone; yellow for LV zone; red for the nonvisible area; orange for areas where only the gestures made at the height of the head are visible).

If we include the results of the regression analysis for the plaza in front of Pyramid No 3 in Tikal, the area of the AV is 2771.4 m^2, and the area of the LV is 1721.16 m^2 for the first class of gestures (Fig. 7).

Figure 7: Results of the first class of gesture visibility analysis for Pyramid No 3 in Tikal with regression (colour code as for Fig. 6).

The next step was to study the visibility of the second class of gestures using the results of visibility regression analysis. In this case, we have three levels of visibility: C/NCV (1-0.9), HV (0.9-0.7), and AV (0.7-0.4), which correspond to the ranges 0-15 m, 15.1-92 m and 92.1-207 m from the speaker. The last level of visibility (LV) was not considered because it extends beyond the venue. The area of the C/NCV covers 245.56 m^2, the area of the HV covers 5914.63 m^2, and the area of the AV covers 2016.11 m^2 (Fig. 8).

The results of the visibility of the second class of gestures for Pyramid No 3 in Tikal, including the results of the analysis of regression, indicate that the area of the C/NCV covers only the steps of the pyramid, at the top of which stands the ritual leader, so we have not calculated its area. The area of the HV instead covers 5924.98 m^2 and the area of the AV 20688.88 m^2. In this case, we did not consider the areas occupied by other buildings or the water bodies indicated in the model (Fig. 9).

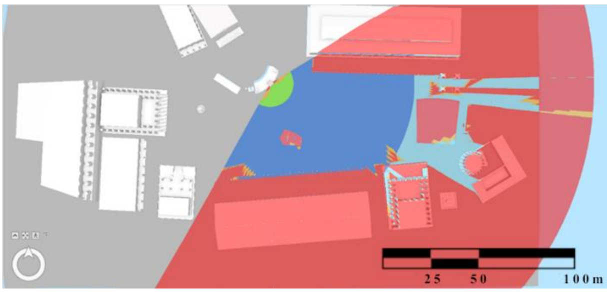

Figure 8: Results of the second class of gesture visibility analysis for the LR Forum Romanum with regression (Green for C/NCV zone; dark blue for HV zone; light blue for AV zone; red for the nonvisible area; orange for areas where only the gestures made at the height of the head are visible).

Our research shows that considering the maximum visibility of the first class of gestures, the area of the Forum Romanum where gestures were visible represents 44.8% of the total available area of the square. Due to the much larger space theoretically available at Pyramid No 3 in Tikal, this ratio is only 16.7%. If – taking into account the results of the regression analysis – we consider only the AV area, the first class of gestures was visible from 36.6% of the theoretically available space at the LR Forum Romanum in Rome and from only 10.1% of that space in Tikal.

The second class of gestures, however, remained visible for both case studies over the entire theoretically available surfaces. When considering the results of the regression analysis of this class of gestures, the C/NCV area for the LR Forum Romanum comprises 2%, the C/NCV+HV area 49.3%, and the C/NCV+HV+AV area 65.4% of the theoretically available area. At Pyramid No 3 in Tikal, the C/NCV surface was located on the steps of the temple, so we did not consider it in the analyses; the HV area covered 21.5% and HV+AV covered 97.8% of the theoretically available space.

4. Estimating crowd size

The results of the visibility analyses are expressed on maps showing the area where gestures were visible enough to be recognized. From these, we calculated the sizes of the crowds. The average person occupies about 0.2 m^2. Therefore, theoretically, it is possible for five people to fit on 1 m^2. In reality, modern public speaking research shows that crowd density varies between one and four people per square meter, sometimes in exceptional situations – and usually for a short time – exceeding the theoretical limit of five people per square meter (Still, 2014). Theoretically, therefore, the LR Forum Romanum could have accommodated a maximum of

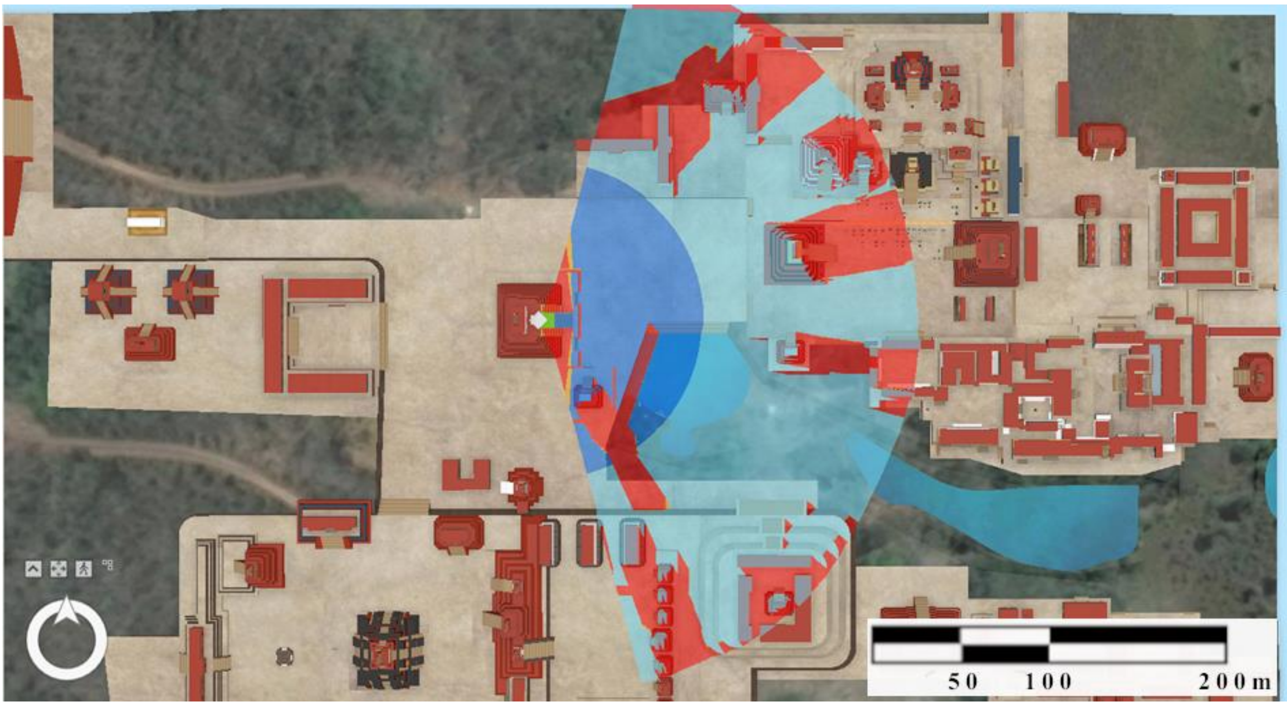

Figure 9: Results of the second class of gesture visibility analysis for Pyramid No 3 in Tikal with regression (colour code as for Fig. 8).

approx. 62500 persons[3] and pyramid No 3 in Tikal a maximum of approx. 137500 persons. Based on this we first calculated the size of the crowd of people who could see the gestures of the different classes considering different scenarios, involving crowd densities between one and five people per square metre. The results for the first class of gestures in the LR Forum Romanum are shown in Table 10, with a mean (for the case of three persons per square meter) of approx. 16803 persons.

Table 10: Calculation of crowd size for the LR Forum Romanum for the maximum visibility of the first class of gestures.

Area[1]	*1*[2]	*2*[2]	*3*[2]	*4*[2]	*5*[2]
5600.94	5600.94	11201.88	16802.82	22403.76	28004.7

Note:
[1]*Area in* m^2
[2]*No of persons/*m^2*.*

The results for the first class of gestures in the case of Tikal are shown in Table 11 with a mean (for the case of three persons per square meter) of approx. 13752 persons.

Table 11: Calculation of crowd size for Pyramid No 3 in Tikal for the maximum visibility of the first class of gestures.

Area[1]	*1*[2]	*2*[2]	*3*[2]	*4*[2]	*5*[2]
4583.98	4583.98	9167.96	13751.94	18335.92	22919.9

Note:
[1]*Area in* m^2
[2]*No of persons per 1*m^2*.*

However, since at similar public events the density of the crowd is usually higher closer to the speaker and it decreases with distance (Still, 2014), we calculated the crowd size assuming that in areas of the C/NCV the crowd density was five persons per square meter, in the areas of the HV it was four persons per square meter, in the areas of the AV it was three persons per square meter, and in the areas of the LV it was two persons per square meter. A similar methodology has previously been used to estimate crowding for acoustic analysis results (Kopij & Pilch, 2019). In this case, for the LR Forum Romanum, the crowd of people who might have seen the first class of the speaker's gestures is 15782 persons, and for Tikal it is 11757 persons (see Table 12).

Table 12: Calculation of crowd size for both case studies for the first class of gestures including the results of the regression analysis.

LR Forum Romanum			*Pyramid no 3 in Tikal*		
Threshold	*Area*[1]	*Crowd est*[2]	*Threshold*	*Area*[1]	*Crowd est*[2]
0-66m (0.7-0.4)	4579.99	13739.97	0-66m (0.7-0.4)	2771.4	8314.2
66.1-83m (0.4-0.2)	1020.95	2041.9	66.1-83m (0.4-0.2)	1721.16	3442.32
	SUM	15781.87		SUM	11756.52

Note:
[1]*Area in* m^2
[2] *No of persons/*m^2 for 0-66 m = 3 *persons/*m^2 *and for* 66.1-83 m = 2 *persons/*m^2*.*

We also applied the above methodology to estimate crowd size when we consider the visibility of the second class of gestures. The results for the LR Forum Romanum shown in Table 13 indicate that the second class of gestures could have been seen in total by just under 31000 of the gathered Romans.

Table 13: Calculation of crowd size for the LR Forum Romanum for the second class of gestures including the results of the regression analysis.

Threshold	*Area*[1]	*Crowd est*[2]
0-15 m (1-0.9)	245.56	1227.8
15.1-92 m (0.9-0.7)	5914.63	23658.52
92.1-207 m (0.7-0.4)	2016.11	6048.33
	SUM	30934.65

Note:
[1]*Area in* m^2
[2] *No of persons per 1*m^2 *for* 0-15m= 5 *persons per 1*m^2*,15.1-92m=* 4 *persons per 1*m^2 *and 92.1-207m=* 3 *persons per 1*m^2*.*

The same analysis for Pyramid No 3 in Tikal (Table 14) shows that the second class of gestures could have been seen by a maximum of about 85750 attendees.

Table 14: Calculation of crowd size for Pyramid No 3 in Tikal for the second class of gestures including the results of the regression analysis.

Threshold	*Area*[1]	*Crowd est*[2]
0-15 m (1-0.9)	0	0
15.1-92 m (0.9-0.7)	5924.98	23699.92
92.1-207 m (0.7-0.4)	20688.88	62066.64
SUM		85766.56

Note:
[1]*Area in* m^2
[2] *No of persons per 1*m^2 *for* 0-15m= 5 *persons per 1*m^2*,15.1-92m=* 4 *persons per 1*m^2*, and 92.1-207m=* 3 *persons per 1*m^2*.*

[3] We can compare this with the estimates of Roman citizens who could fit in the Roman Forum during elections according to Mouritsen and MacMullen. The former estimates the number at 10 000 (Mouritsen, 2001, pp. 20-23), the latter at 15 000-20 000 (MacMullen, 1980, pp. 455–456). These figures seem to be underestimated (as it would mean that the crowd density was at 0.56-1.60 persons per m^2) and should be raised to at least 25 000 people.

5. Conclusion and limitations

The main objective of our study was to determine the maximum distance from which gestures with different levels of detail are visible and to apply the results to analyse the visibility of gestures for two venues distant in time and space. As previous attempts to determine the maximum distance from which gestures are visible were not satisfactory, we conducted our experiment. By analysing its results and performing regression analysis, we were able to determine the maximum distance from which the gestures of two of the three levels of detail (classes of gestures) we distinguished are visible, and the different levels of their visibility.

The results show that less than half (44.8%) of a potential maximum crowd were able to perceive gestures of all levels of detail (classes of gestures) in the case of the LR Forum Roman in Rome and barely 16.7% in the case of Pyramid No 3 in Tikal. These figures are further reduced when we consider the results of the regression analysis, which distinguished four degrees of visibility: complete/nearly complete visibility (C/NCV), high visibility (HV), average visibility (AV), and low visibility (LV). Within each successive degree, a smaller percentage of attendees were able to perceive gestures well enough to identify them, which probably depended on minor differences in visual impairment, contextual clues, gesture distinctiveness, and individual differences in cognitive functioning. Although further experiments are needed to further improve the grading of gesture visibility, the methodology we have presented can be applied to the analysis of any venue, regardless of time and space.

5.1. Limitations

In assuming the conclusions of the visibility analysis, one should keep in mind the limitations of our study. They are primarily related to the experimental procedure we adopted and the underlying premises based on which we decided on the data analysed.

The relatively low survey sample sizes call for some caution in the interpretation of study results. Although experimental research in cognitive psychology accepts similarly sized samples, it seems likely that our results would differ slightly if we could conduct studies with more participants. It is possible that the maximum visibility would have been identified at different milestones – especially in those cases where we obtained surprising visibility results at milestones far from the mock speaker.

Unfortunately, as the research was conducted at the height of the COVID-19 pandemic, our procedure was tailored to the restrictions on the number of people congregating at a single site (max. 6 people). Furthermore, due to low access to volunteers (resulting from the lack of students during the online teaching period), the study was extended over time and thus weather conditions could not be controlled for.

As far as the adopted methodology of statistical analyses is concerned, it is worth emphasizing that in the case of the regression analysis the relatively low number of observations (i.e., the number of milestones) can be considered a limitation. However, adopting a different approach – e.g., testing visibility at every meter – would be hazardous in research with human participants. The study could result in the habituation of subjects, boredom, and a lack of concentration with prolonged repetition of the same activity. Although the results thus need to be approached with caution, they appear to be relatively consistent and to reflect well the natural processes of decreasing object recognition from a distance. Moreover, it is worth re-emphasizing that our priority was not as much to analyse the visibility regression as to determine the visibility maximum, and considering this the methodology we adopted is consistent with research published in this area of study.

Given the above, it seems that repeating the experiment under more controlled conditions would be beneficial, taking into account both the varying light conditions depending on the weather and time of day as well as the movement of the sun across the sky, the position of which at certain times may have caused glare, thus reducing visibility. We cannot exclude the possibility that the results of the experiment were to some extent influenced by the intra-personal variability in the presentation of the same gestures by our mock speakers. However, given that they had time to train and rehearse the gestures they were to present, as well as the modest gesture sample, we rate this risk as very low.

Moreover, in the described case studies, we have to take into account the fact that the virtual reconstructions used depend on both the state of preservation and the state of research, and therefore may not reflect the past reality in all details. It is possible that in the case of both venues, the space available to the audience was limited by structures neither mentioned by written sources nor with any surviving archaeological traces.

Given these limitations, however, we believe that our study provides a satisfactory description of the realities of listening to and observing speech and rituals in public spaces. They are also an example of how cognitive psychology and social science methodologies can be successfully used to study the past.

Acknowledgements

The study is a part of the project “One, two, three! Can everybody hear me? Can everybody see me? – Acoustics and proxemics of Roman contiones” funded by a research grant from the National Science Centre, Poland under the SONATA15 scheme (project No 2019/35/D/HS3/00105).

The compensation for the participants in the experiment was partly funded by the Faculty of History, Jagiellonian University.

The authors would like to thank Dr Piotr Kołodziejczyk and Dr Łukasz Miszk, who acted as 'mock speakers' showing the gestures, and all the participants of the experiment.

Supplementary files

This article contains supplementary files accessible via https://doi.org/10.4995/var.2023.19315.

References

Aldrete, G. S. (1999). *Gestures and Acclamations in Ancient Rome*. Baltimore: The Johns Hopkins University Press.

Balsdon, J. P. V. D. (1969). *Life and Leisure in Ancient Rome*. New York: McGraw-Hill Book Company.

Bishop, A., & Cartmill, E. A. (2021). The body of hierarchy: Hand gestures on classic Maya ceramics and their social significance. *Ancient Mesoamerica*, *32*(2), 269–283. https://doi.org/10.1017/S0956536120000097

Bornaetxea, T., & Marchesini, I. (2022). r.survey: a tool for calculating visibility of variable-size objects based on orientation. *International Journal of Geographical Information Science*, *36*(3), 1–24. https://doi.org/10.1080/13658816.2021.1942476

Bremmer, J. N., & Roodenburg, H. (1993). *A Cultural History of Gesture*. Cambridge: Polity Press.

Brilliant, R. (1963). *Gesture and Rank in Roman Art: The Use of Gestures to Denote Status in Roman Sculpture and Coinage*. New Haven: Connecticut Academy of Arts and Sciences.

Cairns, D. L. (2005). *Body Language in the Greek and Roman Worlds*. Swansea: Classical Press of Wales.

Cifarelli, M. (1998). Gesture and alterity in the art of Ashurnasirpal II of Assyria. *The Art Bulletin*, *80*(2), 210–228.

Ciura, M. (2015). Hand gestures in courtly scenes depicted on Maya vases. *Estudios Latinoamericanos*, *35*, 5–32. https://doi.org/10.36447/estudios2015.v35.art1

Corbeill, A. (2004). *Nature Embodied. Gesture in Ancient Rome*. Princeton-Boston: Princeton University Press. https://doi.org/10.1515/9780691187808

Fisher, P. F. (1994). Probable and fuzzy models of the viewshed operation. In M. F. Worboys (Ed.), *Innovations in GIS 1: selected papers from the First National Conference on GIS Research UK* (pp. 156–170). London: Taylor & Francis.

Fox, N. S. (1995). Clapping Hands as a gesture of anguish and anger in Mesopotamia and in Israel. *Journal of the Ancient Near Eastern Society*, *23*(1), 49–60.

Freyburger, G. (1988). Supplication grecque et supplication romaine. *Latomus*, *3*, 501–525. https://www.jstor.org/stable/pdf/41540951

Frye, R. N. (1972). Gestures of deference to royalty in ancient Iran. *Iranica Antiqua*, *9*, 102–107.

Gardner, A. J. M. (2022). Tracing the semantics of ancient Maya gestures. In A. J. M. Gardner & C. Walsh (Eds.), *Tracing Gestures: The Art and Archaeology of Bodily Communication* (137-162), London: Bloomsbury Publishing.

Giazzi, E. (2019). Gesti da barbari e gesti di barbari: il caso della Storia Romana di Velleio Patercolo. *Aevum Antiquum*, *19*, 149–166. https://www.torrossa.com/en/resources/an/4761808

Głomb, K. (2020). Does eyewitness guess or recognize?: Bootstrapping face and object identification accuracy. *Psychology and Law*, *10*(3), 73–85. https://doi.org/10.17759/psylaw.2020100306

Graf, F. (1993). Gestures and conventions: the gestures of Roman actors and orators. In J. N. Bremmer & H. Roodenburg (Eds.), *A Cultural History of Gesture. From Antiquity to the Present Day* (pp. 36–58). Cambridge: Polity Press.

Hager, J. C., & Ekman, P. (1979). Long-distance of transmission of facial affect signals. *Ethology and Sociobiology*, *1*(1), 77–82.

Hall, J. (2004). Cicero and Quintilian on the oratorical use of hand gestures. *The Classical Quarterly*, *54*(1), 143–160. https://doi.org/10.1093/cq/54.1.143

Hudson, K. M., & Henderson, J. S. (2022). Gesture, posture and meaning in the Ulúa Cultural Sphere. In A. J. M. Gardner & C. Walsh (Eds.), *Tracing Gestures: The Art and Archaeology of Bodily Communication* (163-180), London: Bloomsbury Publishing.

Jones, J. W. (2019). *She Opens Her Hand to the Poor. Gestures and Social Values in Proverbs*. Piscataway: Gorgias Press.

Keesling, C. M. (2005). Misunderstood gestures: Iconatrophy and the reception of Greek Sculpture in the Roman Imperial period. *Classical Antiquity*, *24*(1), 41–79. https://doi.org/10.1525/ca.2005.24.1.41

Kekes, C. (2021). Speaking bodies: an approach to the Egyptian and Aegean ritual gestures of the Bronze Age (preliminary remarks). In M. Arranz Cárcamo, R. Sánchez Casado, A. Planelles Orozco, S. Alarcón Robledo, J. Ortiz García, & P. Mora Riudavets (Eds.), *Current Research in Egyptology 2019: Proceedings of the Twentieth Annual Symposium, University of Alcalá, 17–21 June 2019* (pp. 1–11). Oxford: Archaeopress.

Kendon, A. (2004). *Gesture: Visible Action as Utterance*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511807572

Kopij, K., & Pilch, A. (2019). The acoustics of Contiones, or how many Romans could have heard speakers. *Open Archaeology*, *5*(1), 340–349. https://doi.org/10.1515/opar-2019-0021

Kron, G. (2005). Anthropometry, physical anthropology, and the reconstruction of ancient health, nutrition, and living standards. *Historia: Zeitschrift Für Alte Geschichte*, *54*(1), 68–83.

MacMullen, R. (1980). How many Romans voted. *Athenaeum*, *58*, 454–457.

Maitland Gardner, A. J. (2017). *Posture and Gesture in Ancient Maya Art and Culture*. (Doctoral dissertation, University College London).

Malina, R. M., Selby, H. A., Buschang, P. H., Aronson, W. L., & Wilkinson, R. G. (1983). Adult stature and age at menarche in Zapotec-speaking communities in the Valley of Oaxaca, Mexico, in a secular perspective. *American Journal of Physical Anthropology*, *60*(4), 437–449. https://doi.org/10.1002/ajpa.1330600405

Mouritsen, H. (2001). *Plebs and Politics in the Late Roman Republic*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511482885

McNeill, D. (1992). *Hand and Mind What Gestures Reveal about Thought*. Chicago: Chicago University Press.

McNeill, D., & Levy, E. T. (1982). Conceptual representations in language activity and gesture. In R. Jaravella & W. Klein (Eds.), *Speech, place, and action. Studies in deixis and related topics* (pp. 271–295). Chichester: Wiley.

Miller, V. E. (1981). *Pose and Gesture in Classic Maya Monumental Sculpture*. (Doctoral dissertation, University of Texas at Austin).

Ogburn, D. E. (2006). Assessing the level of visibility of cultural objects in past landscapes. *Journal of Archaeological Science*, *33*, 405–413. https://doi.org/10.1016/j.jas.2005.08.005

Picard, C. (1936). Le geste de la prière funéraire en Grèce et en Étrurie. *Revue de l'histoire Des Religions*, *114*, 137–157. https://www.jstor.org/stable/23664968

Pina Polo, F. (1989). *Las contiones civiles y militares en Roma*. Zaragoza: Departamento de Ciencias de la Antigüedad, Universidad de Zaragoza.

Ricottilli, L. (2021). Reflections on gestures and words in Terence's comedies. In G. Iurescia, M. Federica, S. Hof, & G. Sorrentino (Eds.), *Pragmatic approaches to drama: Studies in communication on the ancient stage* (pp. 364–381). Leiden: Brill. https://doi.org/10.1163/9789004440265_017

Salvo, G. (2015). I gesti di supplica: forme di linguaggio non verbale tra arte e letteratura. *Eidola: International Journal of Ancient Art History*, *12*, 125–136. https://www.torrossa.com/en/resources/an/3134076

Saunders, E. D. (1985). *Mudrā: A Study of Symbolic Gestures in Japanese Buddhist Sculpture*. New York: Pantheon Books.

Stekelenburg, J. J., & de Gelder, B. (2004). The neural correlates of perceiving human bodies: an ERP study on the body-inversion effect. *Neuroreport*, *15*(5), 777–780. https://doi.org/10.1097/00001756-200404090-00007

Still, G. (2014). *Introduction to Crowd Science*. Boca Raton: CRC Press. https://doi.org/10.1201/b17097

Verhagen, P. (2018). Spatial analysis in archaeology: Moving into new territories. In C. Siart, M. Forbriger, & O. Bubenzer (Eds.), *Digital Geoarchaeology. Natural Science in Archaeology* (pp. 11–25). Cham: Springer. https://doi.org/10.1007/978-3-319-25316-9

Wedde, M. (1999). Talking hands: A study of Minoan and Mycenaean ritual gesture–some preliminary notes. In P. P. Betancourt (Ed.), *Meletemata: studies in Aegean archaeology presented to Malcolm H. Wiener as he enters his 65th year*, vol. 3 (pp. 911–919). Liège: Université de Liège.

Wheatley, D., & Gillings, M. (2000). Vision, perception and GIS: developing enriched approaches to the study of archaeological visibility approaches to the study of archaeological visibility. In G. Lock (Ed.), *Beyond the Map: Archaeology and Spatial Technologies* (pp. 1–27). Amsterdam: IOS Press.