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The language void 10 years on: multimodal primate communication research is still uncommon

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Highlights

- Primate communication research is still largely unimodal
- Different approaches are used across modalities
- Comparing findings across studies is difficult

Human language is thought to have evolved from non-linguistic communication systems present in the primate lineage. Scientists rely on data from extant primate species to estimate how this happened, with debates centering around which modality (vocalization, gesture, facial expression) was a likely precursor. In 2011, we demonstrated that different theoretical and methodological approaches are used to collect data about each modality, rendering datasets incomplete and comparisons problematic (Slocombe et al. 2011). Here, 10 years later, we conducted a follow-up systematic review to test whether patterns have changed, examining the primate communication literature published between 2011 and 2020. In sum, despite the promising progress in addressing some gaps in our knowledge,

systematic biases still exist and multimodal research remains uncommon. We argue that theories of language evolution are unlikely to advance until the field of primate communication research acknowledges and rectifies the gaps in our knowledge.

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INTRODUCTION

To disentangle the origins and evolution of human language, many researchers investigate our closest relatives, the nonhuman primates (hereafter, primates), with the aim to learn more about which aspects of their communication are shared with humans, and which are unique to humans (e.g., Fitch 2005; Arbib et al. 2008; Tomasello 2008). While speech is clearly limited to the human species, non-verbal means of communication, such as gestural, facial and vocal signals, are shared across a variety of primate species including humans. Therefore, comparative researchers have focused on the communicative behaviors and cognitive skills underlying primate communication to identify potential precursors to human language (Call & Tomasello 2007; Fedurek & Slocombe 2011; Zuberbühler 2015; Seyfarth & Cheney 2017). Common approaches include the analysis of communicative repertoires, the investigation of intentional and referential use, social function, and if/how single signals are combined into longer, possibly meaningful sequences (for an overview, see Liebal et al. 2013).

Comparative researchers interested in the similarities between non-verbal communication of nonhuman primates and humans traditionally focus on either gestures, vocalizations, or facial expressions. These unimodal approaches tend to be associated with fundamentally different theoretical frameworks, which fuels the fierce debates about the most promising precursor of human language (vocal, facial or gestural). Thus, theories supporting a vocal origin of language suggest that language built directly on the vocal abilities of our ancestors, relying on the evidence for referential use of vocalizations and meaningful call combinations in nonhuman primates (Seyfarth 2005; Zuberbühler 2005). Theories proposing a gestural origin suggest that spoken language was preceded by a gestural stage using visual, voluntarily controlled signals (Hewes 1992; Corballis 2002), and

highlight the intentional and flexible use of gestures in nonhuman primates (Call & Tomasello 2007). In contrast to gestures, facial expressions and vocalizations are often perceived as involuntary expressions of internal affective states; a view supported by the limited evidence for the learning of novel calls or facial expressions, indicating relatively closed communicative repertoires (Tomasello 2008). Theories suggesting a facial origin of language refer to evidence for the speech-like rhythm of communicative mouth movements in nonhuman primates in support of the hypothesis that such mouth movements represent precursors to human speech (Bergman 2013; Pereira et al. 2020).

However, it is possible that there are systematic differences in how research is conducted across the different means of communication, rendering strong conclusions and comparisons about the cognitive features of each problematic. To test this, in 2011, we conducted a systematic review of primate communication literature covering almost five decades of research (1960-2008) (Slocombe et al. 2011), with focus on the study of vocalizations, gestures and facial expressions. As comparative psychologists, we were interested in the relationship between language evolution and these types of non-verbal signals, and their potential role in the emergence of human language. As these different signal types may have different cognitive underpinnings, we used the term “modality” to refer to vocal, gestural and facial signals. This is different to behavioral ecology approaches, where modality is defined by the sensory channel through which the signal is received in the receiver (e.g. visual or auditory channel; Rowe 1999; Partan & Marler 2005; Higham & Hebets 2013). The debate continues as to how best to label these different types of communicative signals (Fröhlich et al. 2019), but for consistency with our previous work, we will refer to vocal, gestural and facial modalities.

Slocombe et al.'s (2011) review resulted in two major findings: first, the vast majority of research studied only one communicative modality (vocalizations, facial expressions, or gestures), while multimodal approaches investigating two or more modalities and their interactions in an integrated way were rather the exception than the norm (5%). Second, facial, gestural and vocal research each relied on rather different theoretical and methodological approaches. Gestural communication was mainly studied in great apes, mostly in captive settings using both experimental and observational methods, with a focus on the producer of a gestural signal. Facial expressions were mostly studied in monkeys, also mostly in captive settings using observational methods, with a focus on both the producer and receiver. Vocalizations were also mostly studied in monkeys, in both wild and captive populations, typically with experimental methods and with a focus on both producer and receiver. This means that despite the wealth of studies, our review found a lack of facial and vocal research on apes, gestural research in wild populations, and experimental approaches to facial communication. Across modalities, there was also a lack of research with a focus on receivers.

These findings had two important implications: first, there were still considerable gaps in our knowledge about primate communication, and second, findings across modalities were difficult to compare since different theoretical approaches and methods had been used. Therefore, we questioned whether the claims regarding a specific origin of human language – either vocal, gestural, or facial – are legitimate given the existing body of evidence and the unimodal approaches used to study primate communication (Slocombe et al. 2011).

We also proposed several ways of obtaining a more complete picture of primate communication and the potential role of the different modalities for the evolution of human

106 language. First, based on the identified gaps of knowledge, we suggested to specifically
107 target the blind spots, and to conduct more gestural research with monkeys and apes in wild
108 settings, to conduct more vocal and facial research with great apes, and to focus more on
109 receiver behavior across modalities. Second, although unimodal research will continue to be
110 the only option because of methodological constraints, we proposed that "… combining
111 data, ideas and theories from different modalities might yield a better understanding than
112 each can provide alone" (Slocombe et al. 2011, p. 920) and therefore suggested a more
113 integrated, multimodal approach to primate communication, especially where established
114 methods are available (Liebal et al. 2013). Several recent review papers on multimodal
115 communication seem to indicate a growing theoretical consensus on the value of
116 considering a more holistic, multimodal approach to studying communication (Wacewicz &
117 Zywiczynski 2017; Fröhlich & van Schaik 2018; Fröhlich et al. 2019; Singletary & Tecot 2020);
118 however, whether that has been matched by a growth in empirical studies is not yet known.
119 Therefore, the aim of the current paper was to investigate the current state of the art
120 in primate communication research 10 years after our publication pointing to these gaps of
121 knowledge. We conducted a systematic literature review of primate communication
122 research from 2011-2020 using the same procedure as in Slocombe et al. (2011). We aimed
123 to examine if (i) the calls for more integrated multimodal work had been answered and
124 there had been an increase in studies examining two or more modalities and their
125 interactions from 2011-2020 compared to 1960-2008. Next, we focused on unimodal
126 research to investigate if the gaps of knowledge had been addressed with (ii) an increase in
127 gestural research in non-great apes as well as an increase in great ape vocal and facial
128 research; (iii) an increase in experimental approaches in facial research and observational

129 methods in vocal studies; (iv) an increase of gestural and facial research in wild settings; and
130 (v) an increase on signal perception and receiver behavior across modalities.
131
132 METHODS
133 For our systematic literature search, we searched for literature published between
134 2011-2020. We used only two of the previously three data bases (Web of Science and
135 Science Direct), since the third (PrimateLit) has been deaccessioned in 2018. We used the
136 same search terms as in Slocombe et al. (2011): "facial communication OR facial expression*
137 OR facial display OR gestur* OR gestur* communication OR gestur* display OR vocalisation
138 OR vocalization OR call* OR vocal communication OR vocal*" AND "primate* OR ape* OR
139 monkey* OR macaque* OR gorilla* OR baboon* OR vervet OR chimpanzee OR gibbon*".
140 This resulted in a total of 501 publications.
141 From these search results, we excluded studies that did not examine one or several of
142 the three modalities of interest (vocal, gestural and facial communication), therefore
143 excluding studies assessing olfactory or chemical communication only, and any publications
144 that did not address the topic of primate communication. We also excluded articles that did
145 not report original empirical research, used secondary data or were not the primary medium
146 of publication (reviews, meta-analyses, meeting abstracts, conference proceedings, and
147 book chapters). Computational models and machine learning approaches were only included
148 if they used original empirical data. We did not consider technical reports (e.g., how to
149 record vocalizations properly) or biomonitoring (e.g., use of vocalizations to estimate
150 population size), since they did not specifically target primate communication. Finally, we
151 excluded studies investigating primates' responses to human signals or the use of artificial
152 language systems, while we included studies where primates signaled towards humans.

153 This resulted in a dataset of 294 publications. We coded each of these papers using the
154 same criteria as in Slocombe et al. (2011). For each publication, we assessed the investigated
155 "modality" (vocal, gestural, facial or multimodal). Vocal communication included
156 vocalizations or calls usually produced by the vocal cords and specific sounds produced by
157 other body parts, such as whistles or raspberries. Gestural communication involved visual
158 movements of the limbs, head or body postures, but not facial expressions. If they were
159 manual behaviors accompanied by sounds, such as chest beats, they were also considered
160 gestures. Facial communication included communicative movements of the face (facial
161 expressions) or the mouth specifically (sometimes termed orofacial movements or facial
162 gestures).
163 We coded a study as "multimodal" if it investigated more than one modality, and as
164 "multimodal integrated" if it investigated the interaction between signals from different
165 modalities. Some studies investigated facial movements while primates were vocalizing. We
166 considered them multimodal, but not as instances of integrated multimodal communication,
167 as these two modalities are necessarily linked with each other via a common production
168 mechanism. We further examined the "species class" studied (great ape, lesser ape, monkey
169 or prosimian), whether the "research method" used was observational (no manipulation of
170 specific variables, no control conditions) or experimental, and whether the "research focus"
171 was on the producer or receiver of a signal. We also coded the "research environment" and
172 distinguished between wild (free-ranging individuals in their natural habitats) and captive
173 settings (laboratories, zoos, semi-free-ranging and sanctuaries).
174
175 RESULTS

Results are usually presented as proportion or percentages of studies. If studies have used multiple species, research environments, methodological approaches, or research foci, the sum of these percentages may exceed 100%.

Multimodality: Has a larger proportion of primate communication studies been multimodal in the period 2011-2020 compared to 1960-2008?

Fig. 1 illustrates the proportion of primate communication research published each year from 1960-2020. It shows that the number of studies investigating two or more modalities in an integrated way in recent years remains low (N = 6), with no obvious increase in multimodal studies in the decade following the publication of Slocombe et al. (2011). Indeed, a Fisher's exact test showed that the proportion of integrated multimodal research was significantly lower in the 2011-2020 (6/294) compared to the 1960-2008 period (28/553) (P = 0.028). Five additional studies used a multimodal approach, but did not investigate them in an integrated way, as they either considered two modalities that were inherently linked with each other (facial movements produced during vocalizations) or because they studied several modalities, but separately from each other.

Figure 1

Modalities: Is there an increase in gestural research in monkeys as well as vocal and facial research in great apes?

The imbalance in the distribution of studies across modalities found in Slocombe et al. (2011) was still present in the current dataset including 283 unimodal studies: vocal

200 studies remained the most frequently researched modality (N = 201, 71.0%), and
201 substantially less research was conducted in the gestural (N = 54, 19.1%) and facial modality
202 (N = 28, 9.9%).

203 Regarding the consideration of different primate species, a quarter of studies
204 investigated chimpanzees (N = 72, 24.5%), followed by rhesus macaques (*Macaca mulatta,* N
205 = 43, 14.6%) and common marmosets (*Callithrix jacchus,* N = 26, 8.8%), with the latter two
206 most frequently used in neuroscientific studies. When contrasting studies on great apes with
207 those of other primates (lesser apes, monkeys, prosimians) within each of the three
208 modalities, in line with Slocombe et al. (2011), we found that great apes were still
209 differentially represented in research across these three modalities in the latest research
210 period (3 × 2 chi^2-test, $\chi^2_{(2)} = 48.62$, $P < 0.001$).

211 However, Fig. 2 illustrates that – unlike facial studies – vocal and gestural research has
212 shifted to focus more on their corresponding understudied species in recent years. A 2 × 2
213 χ^2-test showed that the proportion of vocal studies with great apes is significantly greater in
214 the recent period (0.22) compared to the 1960-2008 period (0.09; $\chi^2_{(1)} = 20.98$, $P < 0.001$).
215 There was a non-significant increase in gestural research with non-great apes (from 0.22 to
216 0.32; $\chi^2_{(1)} = 1.32$ $P = 0.251$) and a non-significant decrease in the proportion of facial
217 research with great apes between the original (0.24) and recent period (0.11; $\chi^2_{(1)} = 2.31$, $P =$
218 0.128).

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220 ----------

221 Figure 2

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Methodological approaches: Has there been an increase in experimental approaches in facial research and observational methods in vocal studies?

In Slocombe et al. (2011), the proportion of observational and experimental methods varied significantly across modalities, with vocal studies being the most experimental and facial expressions the least. For the current dataset, a 3 × 2 χ^2-test revealed that the proportion of experimental approaches across modalities varied significantly ($\chi^2_{(2)} = 13.21$, $P = 0.001$). However, the pattern was different to the original period, with the highest proportion of experimental work found in facial research (0.64) and the lowest in gestural research (0.24). When each modality was examined individually, the proportion of experimental approaches to facial expressions increased significantly in the current (0.64) compared to the original period (0.36; $\chi^2_{(1)} = 7.48$, $P = 0.006$), while for gestures, the proportion of experimental methods decreased significantly (from 0.49 to 0.24; $\chi^2_{(1)} = 7.08$, $P = 0.008$). In vocal research, the proportion of observational methods increased from 0.47 in the original period to 0.62 in the recent period ($\chi^2_{(1)} = 12.48$, $P < 0.001$).

Research environments: Are there more gestural and facial studies in wild settings?

Slocombe et al. (2011) demonstrated that the majority of research into primate communication was conducted in captivity, while this pattern was reversed in the most recent period, with 57% of studies including data from the wild. However, research environments still differed across modalities in the recent period ($\chi^2_{(2)} = 21.74$, $P < 0.001$, Fig. 3). While there was a similar pattern of most studies in wild settings occurring in the vocal domain, now the least research on wild populations was seen in the facial, not the gestural domain, as was found in the original period.

When each modality was examined individually across the two research periods, there was no increase in facial studies in wild settings in the recent period (0.11) compared to the original period (0.08; $\chi^2_{(1)} = 0.18$, $P = 0.669$). In contrast, significantly more research was conducted in the wild for both vocal and gestural signals: the proportion of gestural studies increased from 0.08 in the original period to 0.46 in the recent period ($\chi^2_{(1)} = 19.40$, $P < 0.001$), and for vocal research, the proportion of studies in wild settings increased from 0.38 to 0.57 ($\chi^2_{(1)} = 18.38$, $P < 0.001$).

Figure 3

Research focus: Is there an increased focus on receiver behavior across modalities?

Slocombe et al. (2011) found that the majority of studies investigated signal production and producer behavior, although this focus varied across modalities. Examination of the recent period indicated that the research focus still varied significantly across modalities ($\chi^2_{(2)} = 8.55$, $P = 0.014$), with most studies examining the receiver found in the facial (0.68), then gestural (0.44), and lastly vocal domain (0.39; Fig. 4). When examining each modality separately across the research periods, the proportion of vocal studies with focus on the receiver remained stable over the two periods (0.38 vs 0.39; $\chi^2_{(1)} = 0.09$, $P =$ 761). In contrast, for both facial and gestural research, the proportion of studies investigating the perception of these signals and the corresponding receiver behavior increased significantly in the recent period compared to the original period (facial: 0.39 to 0.68; $\chi^2_{(1)} = 7.49$, $P = 0.006$; gestural: 0.20 to 0.44; $\chi^2_{(1)} = 7.39$, $P = 0.007$).

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272 Figure 4

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275

276 DISCUSSION

277 The aim of this paper was to assess the current state of the art in primate
278 communication research and to compare it with the main findings of our Slocombe et al.
279 (2011) paper. In 2011, we found that the different modalities of primate communication
280 were not studied in similar ways, as they each attracted different research questions and
281 methods. We argued that this rendered comparisons across modalities difficult if not
282 inappropriate, with serious implications for theories of language evolution and attempts to
283 identify origins of human language.

284 In the current paper, through systematic review of the primate communication
285 literature from 2011 to 2020, we found that there has been no significant shift in focus or
286 move towards a more multimodal approach. Despite our call for the use of multimodal
287 approaches to study primate communication in more comprehensive and integrated ways,
288 the number of such studies has actually decreased.

289 There are various possible reasons why unimodal primate communication research
290 continues to dominate. First, studying multiple modalities is very challenging and requires
291 training in multiple methods. Researchers and their teams have historically specialized in the
292 theoretical approach and corresponding methods of a single modality and may feel they lack
293 the expertise to incorporate another modality. It takes time to change the historical
294 foundations of a research group (and it is also possible that some scientific funding bodies

295 tend to favor tried and tested approaches, and thus more incremental research). The Open
296 Science movement might help to push the field towards a more collaborative space, with
297 shared data and code enabling the adoption of more similar methods across studies. Indeed,
298 specific projects have been established to promote collaboration and sharing of methods,
299 which we hope are successful (e.g. Many Primates project: Many Primates et al. 2019,
300 https://manyprimates.github.io, and PhyloPsy: https://www.phylopsy.org/project).
301 Second, some methods might simply be more suited to one modality over others and
302 are difficult to transfer to others. Playback experiments, for example, allow vocal
303 researchers to explore receiver understanding of signals in captive and wild settings by
304 simulating group member interactions that are occurring out of sight of the receiver.
305 However, the corresponding video playbacks necessary to explore understanding of visual
306 facial and gestural signals would need to be constrained to captive populations. Video
307 playbacks may also require integration with other measures (e.g., eye tracking) to
308 extrapolate receiver understanding of third party interactions. Thus, although on a
309 theoretical level it is a good idea to create consistency between modalities, in practice this
310 can be very difficult and in some cases impossible (Liebal & Oña 2018).
311 Third, there is still inconsistency in the literature and across disciplines in both how the
312 term “multimodal" is used, and what makes multimodality interesting. While some scholars,
313 mostly from the field of comparative psychology, use the term multimodality to refer to
314 combinations of visual signals (e.g., gesture and facial expression) as well as combinations of
315 auditory and visual signals (e.g., vocalization and gesture) (Leavens & Hopkins 2005; Pollick
316 et al. 2007; Liebal et al. 2013; Micheletta et al. 2013; Taglialatela et al. 2015), scholars from
317 the fields of behavioral ecology and evolutionary biology argue that true multimodality must
318 combine sensory modalities, not signal types (Partan & Marler 2005; Higham & Hebets

2013). There were attempts to integrate these perspectives on multimodality from comparative psychology and behavioral ecology by using the term “multicomponent” signals (Micheletta et al. 2013) and to differentiate between bimodal combinations consisting of two sensory modalities (e.g., visual and acoustic components) as opposed to unimodal multicomponent signals (consisting of several components of one sensory modality) (Rowe 1999). However, others use the term multicomponent differently and suggest it may be important to differentiate between the production and perception of multicomponent communication (Holler & Levinson 2019). With a focus on production, they refer to multiplex communication if at least two different articulators are involved in producing a signal, while with regard to perception, they refer to multimodal communication if at least two different sensory channels are involved (Holler & Levinson 2019). This array of definitional suggestions demonstrates that the very same term might be defined and operationalized very differently across disciplines. At the same time, more detailed terminology has been introduced to try and capture the complexity of multimodal communication, but we still seem some way off a shared concept. Taken together, the lack of clear consensus on definitions of multimodal communication, the challenge of developing expertise and confidence with diverse methodologies required for rigorous research in multiple modalities, and difficulties in applying some methodologies consistently across modalities are all likely to have contributed to the low number of multimodal primate communication studies. More extensive collaboration and open provision of training sessions targeting methodologies used in vocal, gestural and facial research are likely needed to assist the field in adopting a more holistic approach to studying communication in primates.

342 Although there has been no increase in multimodal research over the last 10 years,
343 some more promising progress has been made in terms of addressing gaps in our knowledge
344 using unimodal approaches. Considering methodological approaches, there was as a
345 significant increase in experimental work on facial expressions, as well as a significant
346 increase in vocal research based on observational approaches. However, while gesture
347 research had used equal proportions of observational and experimental approaches in the
348 original period, experimental methods decreased significantly in recent years, which may
349 need redressing in the coming years.
350 Regarding research environment, there was a shift from an original focus on captive
351 primates to research on wild populations in the recent period, but this varied across
352 modalities. Although vocalizations are still the most frequently studied modality in wild
353 settings, for gesture research, there was a substantial shift from captive to wild settings,
354 particularly in studies with great apes. However, the gap of knowledge regarding facial
355 expressions of free-ranging primates still exists, as numbers of such studies remained very
356 low throughout the 1960-2020 period.
357 Although the research focus still varied across modalities and despite the majority of
358 research investigating the production side of communication, there was also an increase of
359 studies considering the perception of signals, especially in the facial and gestural domain.
360 Finally, with regard to the investigated species, the call in Slocombe et al. (2011) for
361 more vocal research on great ape species seems to have been answered, with a significant
362 increase in great ape vocal research. However, despite this promising shift, in the 2011-2020
363 period, there remains a significant difference in the proportion of studies that included great
364 apes across the three modalities, with the majority of gestural research conducted with
365 great apes, and the majority of vocal and facial communication focused on non-great ape

366 species. Importantly, almost half of the studies in the current dataset is based on the
367 investigation of only three primate species (chimpanzees, rhesus macaques, common
368 marmosets). Thus, although there are often good reasons for studying these species more
369 than others, it is important to note that our current knowledge about communication across
370 the primate order is not representative, since the majority of research is based on a very
371 limited number of primate species.

372 Our recent review of the literature also highlighted two other important issues within
373 the primate communication field. First, there are still considerable differences in the
374 research effort dedicated to vocal, gestural and facial research: the majority of research is
375 still conducted on vocalizations, and despite a recent relative increase in the proportion of
376 gestural studies, research on modalities other than vocalizations remains scarce. Second,
377 classifications of signals and the modality to which they belong are not consistent and/or
378 vary across studies. For example, a signal can be classified as one modality in one study, but
379 another modality in another study, such as lipsmacks, which are considered facial
380 expressions, facial gestures, gestures or orofacial movements across studies (Ferrari et al.
381 2012; Coudé & Ferrari 2018; Clark et al. 2020). The identification of two separate
382 neuroanatomical routes seems to support the notion of two "types" of facial movements,
383 which differ in the extent of volitional control (Rinn 1984; Parr et al. 2005). Thus, how these
384 movements are classified could be important, but nevertheless this differs across studies.
385 Likewise, primate vocalizations (which use the vocal fold) may or may not be distinguished
386 from sounds (such as whistles, raspberries), which are made with the mouth but are not
387 voiced (Leavens et al. 2004; Lameira et al. 2013). Both signal types are auditory, but likely
388 associated with different physiological and cognitive mechanisms.

Taken together, it is promising that some of the gaps in our knowledge highlighted by Slocombe et al (2011) have started to be addressed: Vocal research in great apes, experimental approaches in facial research, observational approaches in vocal research, and studies considering the receiver and signal perception in the gestural and facial domains have all increased. We hope that these trends continue, but it is important to note that despite this progress from 2011-2020, we still found significant differences in the distribution of studies that focus on great-apes, experimental approaches, wild populations and receiver behavior across the three modalities. In addition, our analyses identified several outstanding gaps in our knowledge, where no significant progress has been made in addressing them in recent year. In particular, gestural research on non-great ape species, facial research on great-ape species, a focus on wild populations in facial research and greater consideration of the receiver in vocal research, need to be addressed in the years to come. Considering the current landscape of primate communication findings and comparative approaches to language evolution, our conclusions are similar to the proposal made in Slocombe et al. (2011): until we have a more complete picture of primate communication across modalities and more comparable research results, it is not possible to reject or support a specific theory of language evolution. Thus, it is important to not interpret the absence of evidence for a trait in a poorly researched area as an absence of ability, although many theories of language evolution and many of corresponding studies present such arguments (Zuberbühler 2005; Tomasello & Call 2019).

CONCLUSION

412 To conclude, despite increasing theoretical consensus on the importance of a
413 multimodal approach for studying primate communication in a more comprehensive way,
414 the vast majority of studies still focus exclusively on either facial expressions, gestures or
415 vocalizations. Within unimodal approaches to primate communication, many of the
416 differences in approach and methodology between vocal, gestural and facial research
417 identified in Slocombe et al (2011) persist: significant differences in the distribution of
418 studies that include great apes and wild populations and the use of experimental
419 approaches, as well as the focus on receiver behavior across the three modalities remain.
420 However, in the last 10 years, significant progress has been made towards addressing some
421 of the gaps in our knowledge, with more experimental research on facial expressions, more
422 vocal work with great ape species, and a shift to work on wild primates, particularly in the
423 gestural domain. Furthermore, human language is increasingly considered multimodal
424 (Vigliocco et al. 2014; Holler & Levinson 2019). As a consequence, theories are emerging that
425 propose a multimodal origin of human language (Wacewicz & Zywiczynski 2017; Fröhlich et
426 al. 2019), which provide a new theoretical framework and may further encourage
427 multimodal approaches in empirical primate communication research.
428

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435

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FIGURE CAPTIONS

Fig. 1. — Number of unimodal (vocal, facial and gestural) and multimodal studies published between 1960 and 2020.

Fig. 2. — Illustration of the percentage of studies in each time period within vocal, gestural and facial research that included great ape species (light grey), or focused exclusively on non-great ape species (dark grey: monkeys, hylobatids, prosimians). In the 1960-2008 period, the number of studies reported were N = 122 for facial, N = 51 for gestural, N = 352 for vocal (Slocombe et al., 2011). In the 2011-2020 period, the number of studies reported were N = 28 for facial, N = 54 for gestural, N = 201 for vocal.

553 Fig. 3. — Percentages of studies conducted in wild and captive settings, shown for each
554 modality for the previous (1960-2008) and the current period (2011-2020).
555

556 Fig. 4. — Percentages of studies investigating the production (signaler behavior) and

557 perception (receiver behavior) in the periods of 1960-2008 and 2011-2020.