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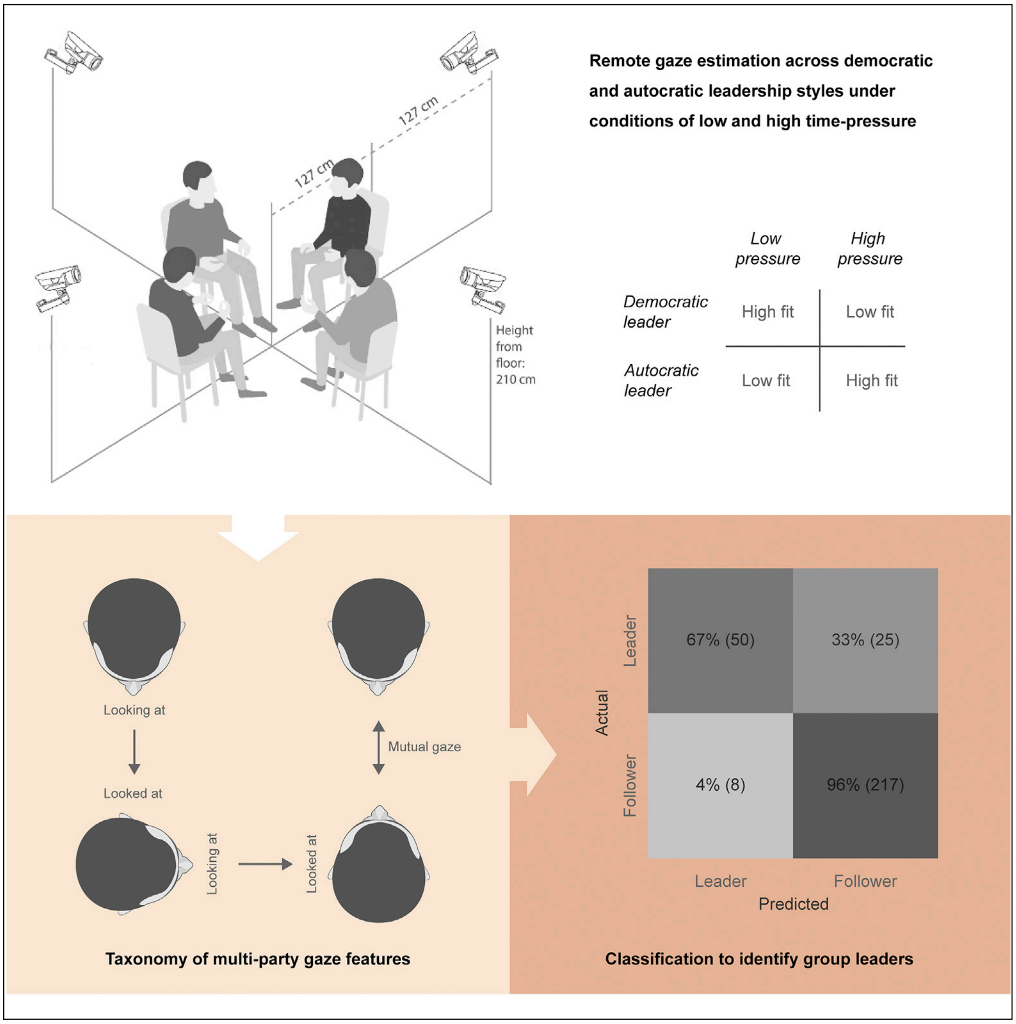

Francesca Capozzi, Cigdem Beyan, Antonio Pierro, ..., Andrew P. Bayliss, Jelena Ristic, Cristina Becchio

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HIGHLIGHTS

Leadership shapes gaze dynamics during real-world human group interactions

Social gaze behavior distinctively identifies group leaders

Identification generalizes across leadership styles and situational conditions

Gaze can serve as a general marker of leadership

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Tracking the Leader: Gaze Behavior in Group Interactions

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SUMMARY

Can social gaze behavior reveal the leader during real-world group interactions? To answer this question, we developed a novel tripartite approach combining (1) computer vision methods for remote gaze estimation, (2) a detailed taxonomy to encode the implicit semantics of multi-party gaze features, and (3) machine learning methods to establish dependencies between leadership and visual behaviors. We found that social gaze behavior distinctively identified group leaders. Crucially, the relationship between leadership and gaze behavior generalized across democratic and autocratic leadership styles under conditions of low and high time-pressure, suggesting that gaze can serve as a *general marker of leadership*. These findings provide the first direct evidence that group visual patterns can reveal leadership across different social behaviors and validate a new promising method for monitoring natural group interactions.

INTRODUCTION

It is commonly believed that leadership is reflected in gaze behavior. Stereotypical thinking links leadership to prolonged gazing toward leaders (Hall et al., 2005) and longer mutual gazing in response to interactions initiated by leaders (Carney et al., 2005). However, evidence for an actual relationship between leadership and social gaze behaviors is limited. To date, investigations on the influence of leadership on gaze behavior have focused on computer-based paradigms that do not provide any opportunity for social interaction (Capozzi and Ristic, 2018; Koski et al., 2015; Risko et al., 2016). The aim of the present study was to develop a novel approach to investigate how leadership shapes gaze dynamics during real-world human group interactions.

Authentic social situations are complex and highly dynamic (Foulsham et al., 2010). What is more, unlike computer-based paradigms, they involve the potential for social interaction and reciprocity. When looking at a representation of a social stimulus (e.g., images of people), individuals need not worry about what their own gaze might be communicating to the stimulus. When looking at real people, in contrast, the eyes not only collect information (encoding function) but also communicate information to others (signaling function; Risko et al., 2016). This dual function of gaze yields an interdependency among multi-agent gaze patterns, which traditional computer-based paradigms, be they static or dynamic scene-viewing tasks, arguably fail to capture (Laidlaw et al., 2011).

Despite a growing understanding of the necessity of studying social cognitive processes in interactive (Schilbach et al., 2013) and complex settings (Frank and Richardson, 2010), little is known about the influence of leadership on gaze-based interactions in unconstrained group interactions. Older studies report that, in dyadic interactions, attribution of power increases as the proportion of looking while speaking increases (Dovidio and Ellyson, 1982; Ellyson et al., 1981; Exline et al., 1975). However, the evidence is inconclusive as to whether gazing decoupled from speaking time identifies leaders (Hall et al., 2005). Moreover, it remains unclear whether the same dynamics constraining dyads also constrain group interactions.

A major reason for the lack of studies investigating group gaze-based interactions is the difficulty of simultaneously tracking transient variations in multi-party gaze features to capture the implicit semantics of social gaze behaviors. In the attempt to overcome these limitations, in this study, we developed a novel tripartite approach combining (1) computer vision methods for remote gaze-tracking, (2) a detailed taxonomy to encode the implicit semantics of multi-party gaze features, and (3) advance machine learning methods to establish dependencies between leadership and visual behaviors during unconstrained group interactions involving four people simultaneously. The basic idea for establishing a relationship between

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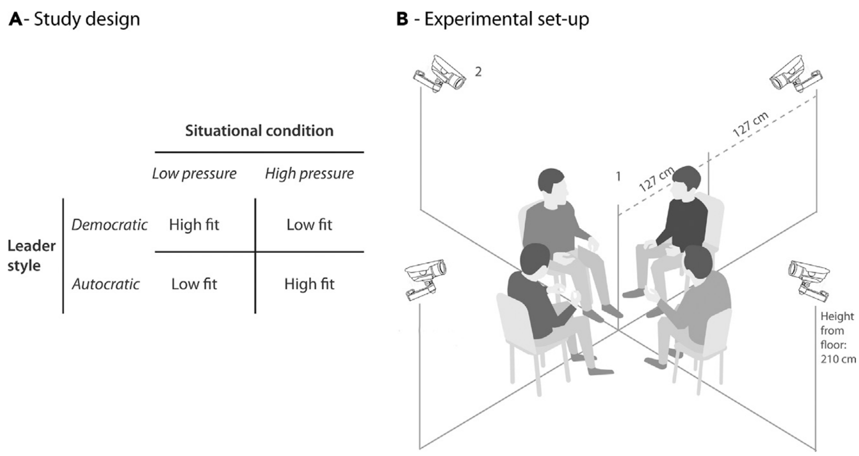

Figure 1. Study Design and Experimental Setting

(A) Study design and manipulation of leadership style and situational condition.

(B) Schematic reproduction of the experimental setting (drawing not to scale). Participants seated on four equidistant chairs (1), while four individual video-cameras were recording the upper part of their bodies (2).

social gaze behavior and leadership was to conceptualize multi-party gaze features as *patterns* and to treat the analysis as a *pattern classification problem*: can a classifier applied to the visual behavior pattern of real people interacting in small groups reveal the leader? This is the first question we addressed in the study described here. The second question is whether the relationship between gaze behavior and leadership generalizes across leadership styles and situational conditions—in other words, whether gaze behavior can serve as *a general marker* of leadership.

Drawing on ideas from social psychology (Chemers, 2014; Foels et al., 2000; Livi et al., 2008; Northouse, 2016), we analyzed gaze-based interaction dynamics in four leadership settings resulting from the orthogonal manipulation of leadership style (i.e., Democratic versus Autocratic) and situational condition (i.e., Low time-pressure versus High time-pressure). Democratic leadership is expected to be more effective under situational conditions of low time-pressure, whereas autocratic leaderships are expected to be more effective under situational conditions of high time-pressure (Fiedler, 2006; Pierro et al., 2003). The orthogonal manipulation of leadership styles and situational conditions resulted in two high-fit conditions (Democratic-Low time-pressure, Autocratic-High time-pressure) and two low-fit conditions (Democratic-High time-pressure, Autocratic-Low time-pressure) (Figure 1A; see also Supplemental Information and Figure S1 for group composition and manipulation checks). Each group, composed of one designated leader and three followers, was assigned a survival task to solve within a limited time (see Figure 1B for the experimental setting). First, using a method for automatically estimating the Visual Focus of Attention (VFOA; Ba and Odobez, 2006; Beyan et al., 2016; Gatica-Perez, 2009; Stiefelhagen et al., 1999), we determined "who looked at whom." Then, we established a detailed taxonomy of multi-party gaze behaviors and, combining the VFOA of individual group-members, reconstructed the gaze-based interaction dynamics. Next, we probed the actual association between leadership and gaze patterns by asking whether a pattern classification algorithm could discriminate leaders and followers among the group-members. After finding evidence for leadership classification, we finally tested whether the classifier was able to generalize across leadership styles, situational conditions, and time.

RESULTS

Extraction of the Visual Focus of Attention

First, using a method for automatically estimating the VFOA (Beyan et al., 2016), we determined "who looked at whom." To do so, we recorded the visual behavior of 16 groups composed of four previously unacquainted individuals over a period of maximum 30 min (mean = 23 min, range = 12–30). Individuals were sitting on four equidistant chairs (Figure 1B, 1). The visual behavior of each individual was simultaneously captured by four multi-view streaming cameras (1,280 × 1,024 pixel resolution, 20 frames per second frame rate) (Figure 1B, 2). In addition, a standard camera (440 × 1,080 pixel resolution, and 25 frames per second

Multi-Party Gaze Feature	Operationalization	Indexed on	Dimension
Looking at	Video-frames in which each individual looked at another member while not looked back	Total video-frames	Participation
Looked at	Video-frames in which each individual was looked at while not looking back	Total video-frames	Prestige
Looked at_multiple	Video-frames in which each individual was looked at by two[a] members simultaneously, while not looking back at any of them	Total video-frames	
Looked at_Ratio	Ratio between "Looked at" and "Looking at"	NA	
Mutual gaze	Video-frames in which each individual was looking at someone while simultaneously being looked back	Total video-frames	Mutual engagement
Mutual gaze_multiple	Video-frames in which each individual was looked at by two[a] members simultaneously, while looking back at one of them	Total video-frames	
Mutual gaze initiation	Frequency of mutual engagement episodes initiated	Total mutual engagement episodes in each video	
Mutual gaze response time	Video-frames between the initiation of a mutual engagement episode and the reaction of the looked at person	Total video-frames	

Table 1. Gaze Behavior Taxonomy: Description, Operationalization, and Social Dimensions of Visual Features

[a]Note: For both Looked at_multiple and Mutual gaze_multiple, the number of video-frames in which an individual was looked at by three members simultaneously did not result in values different from zero, thus these features were omitted from subsequent analyses.

frame rate) was used to capture the whole scene. An automated extraction technique was used to estimate the frame-by-frame VFOA of each participant (Beyan et al., 2016). The performance of the SVM classifiers used to model the individual VFOAs yielded an average of 72% detection rate (see "Visual Focus of Attention" in Transparent Methods).

Reconstruction of Group Interaction Dynamics

Having determined the VFOA of each participant, we proceeded to reconstruct the gaze-based interaction dynamics by combining the VFOA of individual group-members. To this aim, we derived a detailed taxonomy of multi-party gaze on the basis of the three broad social dimensions classically used in the study of social gaze behavior (Capozzi and Ristic, 2018; Emery, 2000; Jording et al., 2018; Kleinke, 1986; Pfeiffer et al., 2013), here labeled participation, prestige, and mutual engagement (see Pierro et al., 2003). Participation refers to the amount of time that each individual looks at others and indicates the individual involvement in interactive dynamics (Ellyson and Dovidio, 1985). Prestige refers to the amount of time that each individual is looked at by others and indicates the extent to which one is referred to during an interaction (Feinman et al., 1992). Mutual engagement refers to the amount of time that each individual looks at someone while looked back and indicates the individual engagement in cooperative behaviors (Foddy, 1978). Within these dimensions, we extracted eight multi-party gaze features to capture comprehensively gaze behavior during group interactions (Table 1; see also Data S1 for gaze behavior data).

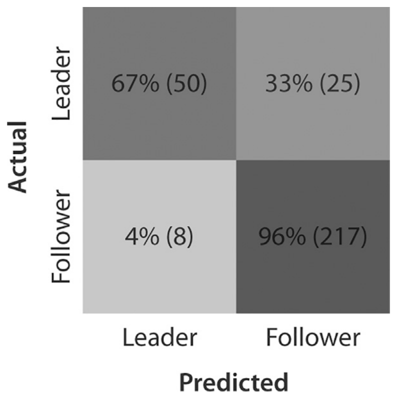

Figure 2. Confusion Matrix for the Leaders versus Followers Classification (Full Dataset, N = 300)

Darker shading denotes higher percentages. The actual number of observations is shown in parentheses.

Leader Classification by Group Visual Behavior

To establish a dependency between visual behavior and leadership, we next trained a linear Support Vector Machine (SVM) to discriminate leaders versus followers on the extracted multi-party gaze features. Classification performance was computed as the resulting average of a leave-one-subject-out cross-validation scheme (Koul et al., 2018).

With a cross-validated accuracy of 89%, classification performance was well above the 0.50 chance level (95% confidence interval [CI] = 0.85, 0.92; kappa = 0.68; sensitivity = 0.86; specificity = 0.90; F1 = 0.75; $p < 0.001$). Figure 2 shows the corresponding confusion matrix.

To investigate which features were more effective for the classification task, we next computed F-scores (see "Leader classification analysis" in Transparent Methods). F-score provides a measure of how well a single feature at a time can discriminate between different classes. The higher the F-score, the greater the ability of a feature to discriminate between leaders and followers. Table 2 provides an overall view of the discriminative power of each visual feature.

Overall, F-scores suggest that leaders looked less at others and, conversely, were looked at more when compared with followers. Also, leaders were involved in and caused more episodes of mutual engagement, relative to followers. The time taken by another group-member to respond to the initiation of mutual engagement was also less for leader-initiated episodes compared with follower-initiated episodes.

Generalization across Leadership Styles, Situational Conditions, and Time

To provide direct evidence that the relationship between leadership and visual behavior generalizes across leadership styles and situational conditions, we next applied Multivariate Cross-Classification (MVCC) analysis to our data (Kaplan et al., 2015). In MVCC, a classifier is trained on one set of data and then tested with another set. If the two datasets share the same patterns, then learning should transfer from the training to the testing set (Kaplan et al., 2015; Kriegeskorte, 2011).

Following this logic, we first applied MVCC analysis to test generalization across leadership styles. We trained a linear SVM to discriminate leaders based on gaze patterns recorded during group interactions with a designated democratic leader and then tested it on group interactions with a designated autocratic leader. With an accuracy of 88%, cross-classification performance was well above the 0.50 chance level (95% CI = 0.82, 0.93; kappa = 0.66; sensitivity = 0.81; specificity = 0.90; F1 = 0.73; $p < 0.001$). Train-autocratic and test-democratic led to a similar cross-classification accuracy of 90% (95% CI = 0.84, 0.95; kappa = 0.72; sensitivity = 0.89; specificity = 0.91; F1 = 0.78; $p < 0.001$).

With a similar logic, we applied MVCC to test generalization across situational conditions. We trained a linear SVM on gaze patterns recorded under high-fit situational conditions (i.e., democratic leaders working in a low time-pressure condition and autocratic leaders working in a high time-pressure condition), and then tested it on group interactions under low-fit situational conditions, and vice versa. Cross-classification performance was once again well above the 0.50 chance level, reaching 94% and 85% for train-high fit and test-low fit (95% CI = 0.89, 0.97; kappa = 0.83; sensitivity = 0.92; specificity = 0.94; F1 = 0.87; $p < 0.001$) and

Feature	F-Score	Leaders Mean ($\pm$SD)	Followers Mean ($\pm$SD)
Looking at	1.800	0.36 $\pm$ 0.09	0.57 $\pm$ 0.13
Looked at_Ratio	1.700	2.43 $\pm$ 1.07	0.85 $\pm$ 0.53
Looked at	1.300	0.72 $\pm$ 0.18	0.43 $\pm$ 0.17
Looked at_multiple	1.300	0.28 $\pm$ 0.13	0.10 $\pm$ 0.08
Mutual gaze	0.780	0.41 $\pm$ 0.14	0.24 $\pm$ 0.12
Mutual gaze_mutiple	0.450	0.26 $\pm$ 0.14	0.15 $\pm$ 0.10
Mutual gaze response time	0.350	0.13 $\pm$ 0.06	0.19 $\pm$ 0.08
Mutual gaze initiation	0.085	0.27 $\pm$ 0.08	0.24 $\pm$ 0.07

Table 2. F-Scores and Group Means for Individual Features for Discrimination between Leaders and Followers (Full Dataset)

Features are ranked based on F-scores, higher values indicating higher contribution to the classification. The unit of measurement for the means is the proportion of frames in which the visual behavior occurred (see Table 1).

train-low fit and test-high fit (95% CI = 0.78, 0.91; kappa = 0.54; sensitivity = 0.82; specificity = 0.86; F1 = 0.63; $p < 0.001$), respectively. Collectively, these data show that multi-party visual behavior supports identification of group leaders across leadership styles (i.e., democratic, autocratic) and situational fit conditions (i.e., high fit, low fit).

Finally, we applied MVCC to test the temporal stability of leadership-related gaze dynamics, that is, whether similar gaze patterns identify leaders over time. To do so, we trained a linear SVM to discriminate leaders based on gaze patterns recorded during the first part of the group task (first half of the video-segments) and then tested it on gaze patterns from the second part of the group task (second half of the video-segments). With an accuracy of 91%, cross-classification performance was well above the 0.50 chance level (95% CI = 0.86, 0.95; kappa = 0.76; sensitivity = 0.90; specificity = 0.92; F1 = 0.81; $p < 0.001$). Training on the second part and testing on the first part led to a similar cross-classification accuracy of 89% (95% CI = 0.83, 0.94; kappa = 0.68; sensitivity = 0.92; specificity = 0.89; F1 = 0.74; $p < 0.001$). These results indicate that leadership-related gaze patterns generalized over time.

DISCUSSION

The study of visual behavior as a nonverbal index of leadership has received attention both within evolutionary perspectives seeking out the ancestral foundations of the human propensity to organize into social structures (van Vugt, 2014), as well as within social neurocognitive perspectives aiming at describing the neural and cognitive processes that enable such structures (Koski et al., 2015). The joint efforts of these disciplines have so far mainly focused on the conditions that predict who will emerge as leader in a particular situation and on the nonverbal cues that signal or predict leadership effectiveness—a computational problem often referred to as "leader index" (Grabo et al., 2017). Albeit important, this approach leaves unaddressed a related but distinct "leader marker" problem: Can the semantics of group visual behavior reveal the leader among group-members?

To address this problem, in the present study, we developed a novel approach combining computer vision methods, a detailed taxonomy of social gaze behaviors, and machine learning methods for pattern classification. We found that social gaze behavior distinctively identified group leaders. Furthermore, leadership identification generalized across different leadership styles and situational conditions. Intriguingly, the features that contributed to classification spanned all the three dimensions of social visual behavior: participation, prestige, and mutual engagement. The association of "prestige" to leadership—leaders being looked at more compared with followers—is consistent with previous findings from computer-based studies. For example, studies investigating gaze allocation in video clips found that people perceived as leaders were fixated more often and for a longer total time compared with people perceived as non-leaders (Foulsham et al., 2010; Gerpott et al., 2018). Could this be because leaders tend to speak more than non-leaders? To address this possibility, we performed an additional MVCC analysis training a linear

SVM to discriminate leaders based on gaze patterns recorded during the video-segments in which the leader spoke the most, and then tested it on the video-segments in which a follower spoke the most. Cross-classification results confirmed that speaking time was not the factor driving leader identification (see Supplemental Information).

A novel finding of our study is that leaders looked less to others when compared with followers. We propose that this distinctive visual behavior of leaders may reflect the signaling function of gaze in authentic social situations (Dovidio and Ellyson, 1982; Kalma et al., 1993). That is, thinking their gaze was being monitored by followers, leaders may have implemented a sort of ''gaze-based impression management'' (Mattan et al., 2017). Similarly, one could hypothesize that followers' recurrent looks toward leaders and promptness to respond to mutual engagement episodes initiated by leaders betrayed a communicative concern, i.e., communicate their interest in leaders' opinions. These hypotheses could be tested by manipulating participants' beliefs about whether or not their own gaze is viewed by others. To the extent that the visual behavior of group-members reflects gaze-based impression management, one would expect the reported patterns to disappear when people believe that they are not seen by others.

To our knowledge, this is the first study that attempts to provide a full characterization of the relationship between leadership and social gaze behavior during natural group interactions. The novel method utilized in the current study demonstrates that gaze-based group behaviors distinctively identified leaders during natural group interactions. Leaders were looked at more, looked less at others, and elicited more mutual gaze. This pattern was observed over time regardless of leadership style and situational condition, suggesting that gaze can serve as *a general marker of leadership*. Together with previous findings on body movements (Badino et al., 2014; Chang et al., 2017; D'Ausilio et al., 2012) and paralinguistic behaviors (Gatica-Perez, 2009; Hall et al., 2005; Schmid Mast, 2002), these results demonstrate the significance of non-verbal cues for leadership identification. We expect that future empirical and modeling studies will investigate whether and how different (and possibly correlated) non-verbal features contribute to leader classification. In addition, we anticipate that these findings will inspire new research questions and real-world applications spanning a variety of domains, from business management (Beyan et al., 2018, 2016) to surveillance and politics (Bazzani et al., 2012).

Limitations of the Study

In the present study, designated leaders were assigned to groups. It will be important for future studies to investigate whether and to what extent the current findings generalize to emergent leadership (e.g., Jiang et al., 2015). In contrast to designated leaders, emergent leaders gain status and respect through engagement with the group and its task. We would expect that, under these conditions, a temporal generalization method using cross-classification over multiple time windows (King and Dehaene, 2014) may identify different gaze-based interaction dynamics depending on the stage of the interaction. The same approach may also reveal how leadership is distributed among group-members across interaction stages.

METHODS

All methods can be found in the accompanying Transparent Methods supplemental file.

SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.isci.2019.05.035.

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AUTHOR CONTRIBUTIONS

Study design, F.C., A.P., and C. Becchio, with the contribution of S.L. and V.M. Assessment of individual dispositions, F.C., with the contribution of A.P. and S.L. Data acquisition, F.C. Visual Focus of Attention, C. Beyan and V.M. Classification analyses, F.C. and A.K., with the contribution of C. Beyan. Manipulation checks, F.C., with the contribution of A.P. and S.L. Data interpretation, all authors. Manuscript preparation, F.C. and C. Becchio, with the contribution of J.R. and A.P.B.; all authors revised and approved the final version of the manuscript.

DECLARATION OF INTERESTS

The Authors report no competing interests.

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REFERENCES

Ba, S.O., and Odobez, J.-M. (2006). A study on Visual Focus of Attention modeling using head pose in a meeting room. In Machine Learning for Multimodal Interaction, S. Renals, S. Bengio, and J.G. Fiscus, eds. (Springer), pp. 75–87.

Badino, L., D'Ausilio, A., Glowinski, D., Camurri, A., and Fadiga, L. (2014). Sensorimotor communication in professional quartets. Neuropsychologia *55*, 98–104.

Bazzani, L., Cristani, M., Paggetti, G., Tosato, D., Menegaz, G., and Murino, V. (2012). Analyzing groups: a social signaling perspective. In Video Analytics for Business Intelligence. Studies in Computational Intelligence, C. Shan, F. Porikli, T. Xiang, and S. Gong, eds. (Springer), pp. 271–305.

Beyan, C., Capozzi, F., Becchio, C., and Murino, V. (2018). Prediction of the leadership style of an emergent leader using audio and visual nonverbal features. IEEE Trans. Multimed. *20*, 441–456.

Beyan, C., Carissimi, N., Capozzi, F., Vascon, S., Bustreo, M., Pierro, A., Becchio, C., and Murino, V. (2016). Detecting emergent leader in a meeting environment using nonverbal visual features only. In Proceedings of the 18th ACM International Conference on Multimodal Interaction (ACM), pp. 317–324.

Capozzi, F., and Ristic, J. (2018). How attention gates social interactions. Ann. N. Y. Acad. Sci. *1426*, 179–198.

Carney, D.R., Hall, J.A., and LeBeau, L.S. (2005). Beliefs about the nonverbal expression of social power. J. Nonverbal. Behav. *29*, 105–123.

Chang, A., Livingstone, S.R., Bosnyak, D.J., and Trainor, L.J. (2017). Body sway reflects leadership in joint music performance. Proc. Natl. Acad. Sci. U S A *114*, E4134–E4141.

Chemers, M.M. (2014). An Integrative Theory of Leadership (Psychology Press).

D'Ausilio, A., Badino, L., Li, Y., Tokay, S., Craighero, L., Canto, R., Aloimonos, Y., and Fadiga, L. (2012). Leadership in orchestra emerges from the causal relationships of movement kinematics. PLoS One *7*, e35757.

Dovidio, J.F., and Ellyson, S.L. (1982). Decoding visual dominance: attributions of power based on relative percentages of looking while speaking and looking while listening. Soc. Psychol. Q. *45*, 106–113.

Ellyson, S.L., and Dovidio, J.F. (1985). Power, Dominance, and Nonverbal Behavior (Springer-Verlag).

Ellyson, S.L., Dovidio, J.F., and Fehr, B.J. (1981). Visual behavior and dominance in women and men. In Gender and Nonverbal Behavior, C. Mayo and N.M. Henle, eds. (Springer), pp. 63–79.

Emery, N.J. (2000). The eyes have it: the neuroethology, function and evolution of social gaze. Neurosci. Biobehav. Rev. *24*, 581–604.

Exline, R.V., Ellyson, S.L., and Long, B. (1975). Visual behavior as an aspect of power role relationships. In Nonverbal Communication of Aggression. Advances in the Study of Communication and Affect, *Vol. 2*, P. Pliner, L. Krames, and T. Alloway, eds. (Plenum Press), pp. 21–52.

Feinman, S., Roberts, D., Hsieh, K.-F., Sawyer, D., and Swanson, D. (1992). A critical review of social referencing in infancy. In Social Referencing and the Social Construction of Reality in Infancy, S. Feinman, ed. (Plenum Press), pp. 15–54.

Fiedler, F.E. (2006). The contingency model: a theory of leadership effectiveness. In Small Groups: Key Readings, J.M. Levine and R.L. Moreland, eds. (Psychology Press), pp. 369–382.

Foddy, M. (1978). Patterns of gaze in cooperative and competitive negotiation. Hum. Relat. *31*, 925–938.

Foels, R., Driskell, J.E., Mullen, B., and Salas, E. (2000). The effects of democratic leadership on group member satisfaction: an integration. Small Gr. Res. *31*, 676–701.

Foulsham, T., Cheng, J.T., Tracy, J.L., Henrich, J., and Kingstone, A. (2010). Gaze allocation in a dynamic situation: effects of social status and speaking. Cognition *117*, 319–331.

Frank, T.D., and Richardson, M.J. (2010). On a test statistic for the Kuramoto order parameter of synchronization: an illustration for group synchronization during rocking chairs. Phys. D Nonlinear Phenom. *239*, 2084–2092.

Gatica-Perez, D. (2009). Automatic nonverbal analysis of social interaction in small groups: a review. Image Vis. Comput. *27*, 1775–1787.

Gerpott, F.H., Lehmann-Willenbrock, N., Silvis, J.D., and van Vugt, M. (2018). In the eye of the beholder? An eye-tracking experiment on emergent leadership in team interactions. Leadersh. Q. *29*, 523–532.

Grabo, A., Spisak, B.R., and van Vugt, M. (2017). Charisma as signal: an evolutionary perspective on charismatic leadership. Leadersh. Q. *28*, 473–485.

Hall, J.A., Coats, E.J., and LeBeau, L.S. (2005). Nonverbal behavior and the vertical dimension of social relations. Psychol. Bull. *131*, 898–924.

Jiang, J., Chen, C., Dai, B., Shi, G., Ding, G., Liu, L., and Lu, C. (2015). Leader emergence through interpersonal neural synchronization. Proc. Natl. Acad. Sci. U S A *112*, 4274–4279.

Jording, M., Hartz, A., Bente, G., and Vogeley, K. (2018). The "social gaze space": gaze-based communication in triadic interactions. Front. Psychol. *9*, 226.

Kalma, A.P., Visser, L., and Peeters, A. (1993). Sociable and aggressive dominance: personality differences in leadership style? Leadersh. Q. *4*, 45–64.

Kaplan, J.T., Man, K., and Greening, S.G. (2015). Multivariate cross-classification: applying machine learning techniques to characterize abstraction in neural representations. Front. Hum. Neurosci. *9*, 151.

King, J.R., and Dehaene, S. (2014). Characterizing the dynamics of mental representations: the temporal generalization method. Trends Cogn. Sci. *18*, 203–210.

Kleinke, C.L. (1986). Gaze and eye contact: a research review. Psychol. Bull. *100*, 78–100.

Koski, J.E., Xie, H., and Olson, I.R. (2015). Understanding social hierarchies: the neural and psychological foundations of status perception. Soc. Neurosci. *10*, 527–550.

Koul, A., Becchio, C., and Cavallo, A. (2018). PredPsych: a toolbox for predictive machine learning-based approach in experimental psychology research. Behav. Res. Methods *50*, 1657–1672.

Kriegeskorte, N. (2011). Pattern-information analysis: from stimulus decoding to computational-model testing. Neuroimage *56*, 411–421.

Laidlaw, K.E.W., Foulsham, T., Kuhn, G., and Kingstone, A. (2011). Potential social interactions are important to social attention. Proc. Natl. Acad. Sci. U S A *108*, 5548–5553.

Livi, S., Kenny, D.A., Albright, L., and Pierro, A. (2008). A social relations analysis of leadership. Leadersh. Q. *19*, 235–248.

Mattan, B.D., Kubota, J.T., and Cloutier, J. (2017). How social status shapes person perception and evaluation: a social neuroscience perspective. Perspect. Psychol. Sci. *12*, 468–507.

Northouse, P.G. (2016). Leadership: Theory and Practice, Seventh Edition (SAGE Publications).

Pfeiffer, U.J., Vogeley, K., and Schilbach, L. (2013). From gaze cueing to dual eye-tracking: novel approaches to investigate the neural correlates of gaze in social interaction. Neurosci. Biobehav. Rev. *37*, 2516–2528.

Pierro, A., Mannetti, L., De Grada, E., Livi, S., and Kruglanski, A.W. (2003). Autocracy bias in informal groups under need for closure. Personal. Soc. Psychol. Bull. *29*, 405–417.

Risko, E.F., Richardson, D.C., and Kingstone, A. (2016). Breaking the fourth wall of cognitive science: real-world social attention and the dual function of gaze. Curr. Dir. Psychol. Sci. *25*, 70–74.

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., and Vogeley, K. (2013). Toward a second-person neuroscience. Behav. Brain Sci. *36*, 393–414.

Schmid Mast, M. (2002). Dominance as expressed and inferred through speaking time: a meta-analysis. Hum. Commun. Res. *28*, 420–450.

Stiefelhagen, R., Finke, M., Yang, J., and Waibel, A. (1999). From gaze to focus of attention. In Visual Information and Information Systems: Third International Conference Visual '99, D. Huijsmans and A.W.M. Smeulders, eds. (Springer), pp. 765–772.

van Vugt, M. (2014). On faces, gazes, votes, and followers: evolutionary psychological and social neuroscience approaches to leadership. In New Frontiers in Social Neuroscience, J. Decety and Y. Christen, eds. (Springer (IPSEN foundation)), pp. 93–110.

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Supplemental Information

Tracking the Leader: Gaze Behavior in Group Interactions

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SUPPLEMENTAL INFORMATION

Transparent Methods

Participants

We choose a sample size of 64 based on a power analysis on pilot data (power analysis: r = .4, α = .05, β = .05, Faul et al., 2007; see also the Supplemental Analyses below). All participants (44 females, 20 males; mean age = 21.59 years, age range = 19-29) were naïve to the purpose of the experiment, provided written informed consent, and were compensated with 8 Euros for their participation. The study was conducted in accordance with the ethical principles of the World Medical Association declaration of Helsinki 2008 and was approved by the Bio-Ethical Committee of the University of Torino.

Assessment of individual dispositions. Group composition and leadership designation were based on participants' individual dispositions to leadership and to leadership styles. Those dispositions were determined with reference to a larger pool of participants six months before the experiment, when voluntary students of the University of Torino (N = 274; 211 females, 63 males; mean age = 20.59, age range = 19-37) were asked to complete the Systematic method for the Multiple Level Observation of Groups (SYMLOG; Blumberg and Hare, 1999; Polley et al., 1988). The SYMLOG is a comprehensive instrument designed to evaluate individual dispositions along three bipolar dimensions: Dominance vs. Submissiveness; Acceptance vs. Non-acceptance of (Task Orientation of Established) Authority; Friendliness vs Unfriendliness. Based on the median split of the Dominance and Task Orientation scores, participants were identified as potential leaders or potential followers. Potential leaders were further subdivided into democratic leaders and autocratic leaders based on the median split of the Friendliness scores. This procedure was applied to male and female participants separately (see also Supplemental Analyses for the "Composition of groups").

Group composition. Participants were assigned to one of four-person groups, for a total of sixteen groups. Each experimental group was homogenous for gender (5 all-male groups; 11 all-female groups). Eight participants classified as leaders with a democratic leadership style and eight participants classified as leaders with an autocratic leadership style were randomly assigned as 'designated leaders' to one of the sixteen groups. Forty-eight of the potential followers were also randomly assigned to each group (see also Supplemental Analyses for the "Composition of groups").

Procedure

Setting. Four equidistant chairs were placed at the centre of an otherwise non-furnished room (Figure 1 B in the main text). The chairs were placed with a cross displacement, each chair being 127 cm distant from the centre (Figure 1 B.2 in the main text). Four AXISP1346 multi-view streaming cameras (1280x1024 pixels resolution, 20 frame per second frame rate) were fixed to the ceiling at a height of 210 m from the floor and at a distance of approximately 127 cm from the chairs and were used for individual video recording of the upper part of the body (head and shoulders) of each group member. These individual videos were used for VFOA modelling and visual behaviour features extraction. In order to create videos for use in the leadership perception manipulation check, a standard camera (440x1080 pixels resolution, and 25 frame per second frame rate) was placed at an approximate distance of 200 cm from the chairs to capture the whole scene.

Group task. Each group of participants was asked to complete one of two versions of a survival task ("Winter" or "Desert"; Johnson and Johnson, 1994). The task involved rank-ordering 12 ordinary items (e.g., a map, a mirror, a chocolate bar) based on their utility for group-surviving in a hostile environment. The use of pen paper was not allowed; the experimenter repeated the list of items twice before leaving the room. Participants were invited to contribute to the discussion allowing the leader to make a final decision (Johnson and Johnson, 1994). Performance scores were obtained by subtracting the rank given to each item from the optimal rank (established by survival experts). The final score was given by the sum of the absolute values of these differences.

Time-pressure manipulation. To manipulate situational conditions, a time-pressure manipulation was applied (Chirumbolo et al., 2004; De Grada et al., 1999; Kruglanski and Freund, 1983; Pierro et al., 2003). Groups assigned to the *high time-pressure* situation (n = 8) were instructed to perform the assigned task as quickly as possible, with a clear instruction that time was a critical demand to their task. Groups assigned to the *low time-pressure* situation (n =8) were instead encouraged to take their time to reach a decision with no specific time demand. In the high time-pressure condition, twenty minutes after the start of the session, the experimenter entered the room and urged participants to complete the task. In the low time-pressure condition, twenty minutes after the start of the session, the experimenter entered the room and invited participants to complete the task. In both cases, the maximum time allowed was thirty minutes. Post-hoc debriefing sessions confirmed the validity of the time-pressure manipulation, in that participants in the high time-pressure condition (but not those in the low time-pressure condition) reported the they had perceived time as a critical demand to their task.

Post-task questionnaires. At the end of the group task, group members completed three questionnaires: a report of satisfaction and stress, the General Leadership Impression (GLI) scale to measure leadership perception (Lord et al., 1984; Zaccaro et al., 1991), and the Implicit Followership Theories (IFT) scale to assess participants' personal assumptions about followership (Avolio et al., 2009; Sy, 2010).

Analysis of gaze behaviour

Visual Focus of Attention. To ensure an adequate sampling of observations, the videos of the 16 group interactions (N = 64 individual observations) were divided into 75 video-segments (N = 300 individual observations). The video-segmentation was performed such that all segments had approximately the same duration (i.e., between 4 and 5 minutes). In case the duration of a video was not divisible by 4 or 5, the remaining seconds were evenly distributed across the video-segments of that video. This operation resulted in an average duration of 5 minutes (range = 4-6), with the exception of one segment lasting 2 minutes due to processing issues, for an average of 5 segments per group (range = 2-6). The Constrained Local Model (CLM) was applied to each video-segment to detect and track facial landmarks (Cristinacce and Cootes, 2006). To model the frame-by-frame VFOA of each participant, participants' VFOAs were annotated by two annotators for 25600 randomly selected frames (400 frames for each video determined by the confidence level=90% and margin error=4%). Annotators were asked to determine whether a participant was looking at the person in front/at the right/at the left or at no-one. A total of 23000 frames (an average 359.4 per video with standard deviation of 46.54) were retained based on the agreement between the annotators. The annotated VFOA data were randomly divided into training and validation sets (100 repetitions) to learn the SVM model (radial basis kernel function, RBF) with varying kernel parameter. The cost function, the random under sampling, and the SMOTE methods were combined with SVM. For each video, the method performing the highest geometric mean of the detection rates was selected to classify the whole unlabelled head pose; this procedure was applied independently to each video-segment (Beyan et al., 2016). To reduce noise, a smoothing filter with a 5 frames window was applied to the VFOA result obtained from SVM predictions.

Leader classification analysis. Gaze features of interest were extracted and used as predictors for the leader classification analysis. A linear Support Vector Machine (SVM) with a leave-one-subject-out cross-validation scheme was utilized to solve the classification task (i.e., discriminating between leaders vs. followers based on visual features). Linear SVM was chosen to avoid overfitting while also ensuring an optimal function to separate the data classes (Ben-hur and Weston, 2010; Gokcen and Peng, 2002; Hsu et al., 2010). As the features were already indexed on a common scale, data were not rescaled prior to the analyses.
The classification performance was assessed based on the following criteria: classification accuracy (defined as the percentage of the number of individuals classified correctly over the total individuals), Kappa (i.e., proportion of correctly classified individuals after accounting for the probability of chance agreement), Sensitivity (i.e., true positive rate), Specificity (i.e., true negative rate), and F1 (i.e., the harmonic mean of Sensitivity and Specificity). Finally, we tested the statistical reliability of the classification results with a 1000-repetition permutation test, a non-parametric test which randomly rearranged 1000 times the labels of observed data points to calculate the distribution of the test statistic under the null hypothesis (Ojala and Garriga, 2010).
To estimate the relative contribution of gaze features for leadership prediction, we used a simplified Fisher criterion (F-score criterion). F-score provides a measure of how well a single feature at a time can discriminate between different classes. The higher the F-score, the better the discriminatory power of that feature. The F-score was computed in the same way as the classic Fisher criterion (Duda et al., 2012) (see Table 2 in the main text for the corresponding results).
All classification analyses were performed with the PredPsych package written in R (Koul et al., 2018).

Supplemental Analyses

Composition of groups

Figure S1 shows the distributions of the scores that the subjects of the participant pool obtained at each of the SYMLOG subscales (Polley et al., 1988). To select the potential leaders, we first selected participants with a score on the SYMLOG Dominance subscale higher than the median of the sample (females: Me = 4; males: Me = 6). Among these, we then selected the participants with a score on the SYMLOG Task Orientation subscale higher than the median of the sample (females: Me = 4; males: Me = 1). Finally, participants with a score on the Friendliness subscale higher than the median of the sample (Xi = Me + 1) were selected as democratic leaders (females: >18; males: >18), while participants with a score on the Friendliness subscale lower than the median of the sample (Xi = Me - 1) were selected as autocratic leaders (females: <15; males: <14). All other participants could be randomly selected as followers.

Based on participants' availability, we then composed the experimental groups. A series of independent t-tests on the SYMLOG scores of the participants of the experimental groups confirmed that autocratic ($M = 13.00$, $SE = .85$) and democratic ($M = 21.63$, $SE = 1.03$) leaders significantly differed on Friendliness, $t(14) = 6.458$, $p < .001$ (Dominance: $p = .858$, Task orientation: $p = .353$). Consistently, leaders overall significantly differed from the followers on Dominance ($p = .002$), Task orientation ($p < .001$), and Friendliness ($p = .012$). However, autocratic leaders showed a non-significant difference with the followers ($M = 12.12$, $SE = 1.73$) on Friendliness scores ($p = .489$). Taken together, these data show that the differentiation between democratic and autocratic leaders was consistent with the experimental design, although the specificity of autocratic leaders compared to the other participants was weaker than that of democratic leaders.

Manipulation checks

We checked the reliability of our procedure both for establishing leadership as well as for creating different leadership settings.

Leadership perception. As a manipulation check, we administered participants the General Leadership Impression (GLI) scale. GLI is a 5-item scale that asks participants to rate the other members of the group on their contribution to the group's overall effectiveness on the activity (Lord et al., 1984). The range of responses is 1 (nothing) to 5 (extreme amount). Individual GLI scores are calculated by averaging the ratings given by the other three group members. The higher the score on this scale, the higher the leadership perception. All participants, including the designated leaders, filled out the GLI. To obtain an additional independent measure of leadership perception, we also asked two independent observers to watch the videos of the group interactions and complete the GLI for each group member ($ICC = .771$, $p < .001$).

To test the efficacy of our procedures for establishing leadership, the GLI scores obtained by the designated leaders were compared to the average GLI scores obtained by the other group members with a split-plot ANOVA with role (2: leader, follower) as within-subject factor, and leadership style (2: autocratic, democratic) and situational condition (2: low time-pressure, high time-pressure) as between-subject factors. Designated leaders ($M = 3.93$, $SE = .19$) were perceived as showing higher leadership attitudes relative to other group members ($M = 3.25$, $SE = .06$) [$F(1,12) = 9.412$, $p = .010$, $\eta^2_p = .440$], with no apparent influence of leadership style ($p = .414$) or situational condition ($p = .774$). Similar results were obtained when considering the leadership perception scores obtained from independent observers [$F(1,12) = 14.944$, $p = .002$, $\eta^2_p = .555$; other p values ranging from .266 to .766]. Together, these data indicate that designated leaders were perceived as such, both by other group members and by external observers.

Leadership settings. To test the efficacy of our procedures in creating the different leadership settings (see Figure 1 A in the main text), we also assessed group performance, individual reports of satisfaction and stress across conditions.

To evaluate group task performances on the task, a univariate ANOVA was performed on the task scores, with leadership style (2: autocratic, democratic) and situational condition (2: low time-pressure, high time-pressure) as between-subject factors. A similar analysis was applied to the time of interactions. In line with previous evidence showing that situational fit improves group performance (Fiedler, 1971; Higgins, 2008; Strube and Garcia, 1981), analysis of task scores revealed that groups in high fit conditions ($M = 41.5$, $SE = 2.89$) performed better than those in low fit conditions (M = 51.5, SE = 2.56) [$F(2,14) = 5.970$, $p = .031$, $\eta^2_p = .332$; ($t(14) = 2.585$, $p = .022$)].

Satisfaction and stress related to the group interaction were assessed with a 15-items ad hoc questionnaire. Satisfaction was assessed with reference to how they felt satisfied with group performance (2 items) and with individual performance (1 item) and how they felt a in positive mood in relation to the interaction (8 items). Stress was assessed with reference to how they felt pressured by time perception (1 item) and how they perceived a sense of fatigue (3 items). The range of responses was 1 (nothing) to 5 (extreme amount). Since followership attitudes have been associated with perception of relationship quality and satisfaction (Sy, 2010; Uhl-Bien et al., 2014), the results from the Implicit Followership Theories (IFT) scale were included in the analysis of satisfaction and stress as covariates. The IFT is an 18-item scale asks to participants to rate from 1 (not at all characteristic) to 10 (extremely characteristic) the extent to which they associate each adjective item to their idea of followers. The items describing positive attributes (for example, “hardworking”, “enthusiastic”) comprise the sub-scale follower Prototype, whereas items describing negative attributes (for example, “bad temper”, “easy influenced”) comprise the sub-scale follower Anti-prototype (Sy, 2010).

Two separate MANCOVAs were performed on satisfaction reports (group performance, individual performance, positive mood) and on stress reports (time perception and fatigue), with leadership style (2: autocratic, democratic) and situational condition (2: low time-pressure, high time-pressure) as between-subject factors. Scores on followership attitudes (sub-scales follower Prototype and follower Anti-prototype) were included as covariates. All significant main effects were explored with separate univariate ANOVAs.

Analyses revealed that participants’ satisfaction reports were modulated by leadership style [$F(3,56) = 3.162$, $p = .032$, $\eta^2_p = .145$], by the fit between leadership style and situational condition [$F(3,56) = 3.188$, $p = .031$, $\eta^2_p = .146$], and by individual generally positive attributions to followers [$F(3,56) = 5.140$, $p = .003$, $\eta^2_p = .216$]. Specifically, participants in groups with democratic leaders (M = 3.77, SE = .14) reported higher satisfaction in relation to group performance, as compared to participants in groups with autocratic leaders (M = 3.26, SE = .14) [$F(1,59) = 6.467$, $p = .014$, $\eta^2_p = .099$]. These effects were modulated by the fit with the situational condition [$F(1,59) = 5.795$, $p = .019$, $\eta^2_p = .089$], such that the satisfaction for group performance was higher with democratic leaders (M = 4.11, SE = .20) than with autocratic leaders (M = 3.08, SE = .21) only in the low time-pressure condition ($p = .001$), and that in groups with democratic leaders, the satisfaction was higher under low time-pressure, as compared to high time-pressure (M = 3.44, SE = .20) ($p = .026$). Additionally, scores on positive mood were also modulated by the fit between leadership style and situational condition [$F(1,59) = 4.140$, $p = .046$, $\eta^2_p = .066$], in that participants in groups with democratic leaders reported higher positive mood after the interaction (M = 6.617, SE = .24) than participants in groups with autocratic leaders (M = 5.698, SE = .25) only under low time-pressure ($p = .012$). Both the reports of satisfaction for group performance and of positive mood were modulated by individual generally positive attributions to followers, such that the higher positive attributions were associated to higher satisfaction for group performance [$F(1,59) = 8.018$, $p = .006$, $\eta^2_p = .120$; B = .272] and to higher positive mood [$F(1,59) = 14.634$, $p < 0001$, $\eta^2_p = .199$; B = .444].

Analyses on *stress* reports revealed that participant in groups with autocratic leaders (M = 3.406, SE = .24) perceived time as not sufficient to a greater extent than participants in groups with democratic leaders (M = 4.125, SE = .23) [$F(2,57) = 3.193$, $p = .048$, $\eta^2_p = .101$)].

Taken together, these data suggest that the participants’ stress, as indexed by time perception, and participants’ satisfaction, as indexed by the satisfaction for the group performance and the positive mood associated with the interaction, were modulated by the leadership style and, partially, by the fit between the leadership style and situational condition. Specifically, democratic leaders were associated with higher satisfaction, especially in the low time-pressure condition. These results are in line with previous evidence showing that a general preference for democratic leadership is affected by its potential inadequacy to respond to task demands in situations that require straightforward solution strategies (Foels et al., 2000; Gastil, 1994; Kruglanski et al., 2006). All in all, manipulation check analyses confirmed the reliability of our procedure both for establishing leadership as well as for creating different leadership settings.

Control analysis on speaking time

To exclude that our results were simply driven by the proportion of speaking time, we applied MVCC to verify whether gaze behaviour identifies leaders regardless of speaking time. To do so, we trained a linear SVM to discriminate leaders based on gaze patterns recorded during the video-segments in which the leader spoke the most (39 video-segments, corresponding to 156 individual observations), and then tested it on the video-segments in which a non-leader member spoke the most (19 video-segments, corresponding to 76 individual observations). Seventeen video-segments had to be excluded from this analysis due to technical problems in audio recording. With an accuracy of 78%, cross-classification performance was well above the .50 chance level (95% CI = .67, .86; Kappa = 0.26; Sensitivity = 0.63; Specificity = 0.79; F1 = .37; $p < .001$). Training on the video-segments in which a non-leader member spoke the most and testing on the video-segments in which the leader spoke the most led to a cross-classification accuracy of 85% (95% CI = .78, .90; Kappa = .53; Sensitivity = .83; Specificity = .85; F1 = .61; $p = .002$). These results indicate that leadership-related gaze patterns are similar regardless of speaking time.

Data and software availability

Gaze behaviour data are available as Supplemental Information (provided as supplemental Excel table). The original videos of the group interactions are available from the repository of the Istituto Italiano di Tecnologia, https://www.iit.it/research/lines/pattern-analysis-and-computer-vision/pavis-datasets/574-leadership-corpus-dataset. The code to generate the VFOA is available from the Authors VM and CBeyan upon reasonable request. The code for classification analyses is available in Koul et al., 2018.

Supplemental References

Avolio, B.J., Walumbwa, F.O., Weber, T.J., 2009. Leadership: Current theories, research, and future directions. Annu. Rev. Psychol. 60, 421–449. doi:10.1146/annurev.psych.60.110707.163621

Ben-hur, A., Weston, J., 2010. A user's guide to Support Vector Machine, in: Carugo, O., Eisenhaber, F. (Eds.), Data Mining Techniques for the Life Sciences. Methods in Molecular Biology 609. Humana Press, pp. 223–239. doi:10.1007/978-1-60327-241-4

Blumberg, H.H., Hare, A.P., 1999. Sociometry applied to organizational analysis: A review. Int. J. Action Methods 52, 15.

Chirumbolo, A., Livi, S., Mannetti, L., Pierro, A., Kruglanski, A.W., 2004. Effects of need for closure on creativity in small group interactions. Eur. J. Pers. 18, 265–278. doi:10.1002/per.518

Cristinacce, D., Cootes, T., 2006. Feature detection and tracking with constrained local models, in: Chantler, M., Trucco, M., Fisher, B. (Eds.), BMVC 2006 - Proceedings of the British Machine Vision Conference 2006. Edinburgh, pp. 929–938. doi:10.5244/C.20.95

De Grada, E., Kruglanski, A.W., Mannetti, L., Pierro, A., 1999. Motivated cognition and group Interaction: Need for closure affects the contents and processes of collective negotiations. J. Exp. Soc. Psychol. 35, 346–365. doi:10.1006/jesp.1999.1376

Duda, R.O., Hart, P.E., Stork, D.G., 2012. Pattern Classification, 2nd ed. John Wiley & Sons.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39, 175–191. doi:10.3758/BF03193146

Fiedler, F.E., 1971. Validation and extension of the contingency model of leadership effectiveness: A review of empirical findings. Psychol. Bull. 76, 128–148. doi:10.1037/h0031454

Foels, R., Driskell, J.E., Mullen, B., Salas, E., 2000. The effects of democratic leadership on group member satisfaction: An integration. Small Gr. Res. 31, 676–701. doi:10.1177/104649640003100603

Gastil, J., 1994. A definition and illustration of democratic leadership. Hum. Relations 47, 953–975. doi:10.1177/001872679404700805

Gokcen, I., Peng, J., 2002. Comparing linear discriminant analysis and support vector machines, in: Yakhno, T. (Ed.), Advances in Information Systems. Springer-Verlag Berlin Heidelberg, Izmir, Turkey, pp. 104–113. doi:10.1007/3-540-36077-8_10

Higgins, E.T., 2008. Regulatory fit, in: Shah, J.Y., Gardner, W.L. (Eds.), Handbook of Motivation Science. Guilford Press, pp. 356–372.

Hsu, C.-W., Chang, C.-C., Lin, C.-J., 2010. A practical guide to support vector classification, Technical report, Department of Computer Science, National Taiwan University. doi:10.1177/02632760022050997

Johnson, D.W., Johnson, F.P., 1994. Joining Together: Group Theory and Group Skills, 5th ed. Allyn & Bacon.

Kruglanski, A.W., Freund, T., 1983. The freezing and unfreezing of lay-inferences: Effects on impressional primacy, ethnic stereotyping, and numerical anchoring. J. Exp. Soc. Psychol. 19, 448–468. doi:10.1016/0022-1031(83)90022-7

Kruglanski, A.W., Pierro, A., Mannetti, L., De Grada, E., 2006. Groups as epistemic providers: Need for closure and the unfolding of group-centrism. Psychol. Rev. 113, 84–100. doi:10.1037/0033-295X.113.1.84

Lord, R.G., Foti, R.J., De Vader, C.L., 1984. A test of leadership categorization theory: Internal structure, information processing, and leadership perceptions. Organ. Behav. Hum. Perform. 34, 343–378. doi:10.1016/0030-5073(84)90043-6

Ojala, M., Garriga, G.C., 2010. Permutation tests for studying classifier performance. J. Mach. Learn. Res. 11, 1833–1863. doi:10.1109/ICDM.2009.108

Polley, R.B., Hare, A.P., Stone, P.J., 1988. The SYMLOG practitioner: Applications of small group research. Praeger Press.

Strube, M.J., Garcia, J.E., 1981. A meta-analytic investigation of Fiedler's contingency model of leadership effectiveness. Psychol. Bull. 90, 307–321. doi:10.1037/0033-2909.90.2.307

Sy, T., 2010. What do you think of followers? Examining the content, structure, and consequences of implicit followership theories. Organ. Behav. Hum. Decis. Process. 113, 73–84. doi:10.1016/j.obhdp.2010.06.001

Uhl-Bien, M., Riggio, R.E., Lowe, K.B., Carsten, M.K., 2014. Followership theory: A review and research agenda. Leadersh. Q. 25, 83–104. doi:10.1016/j.leaqua.2013.11.007

Zaccaro, S.J., Foti, R.J., Kenny, D.A., 1991. Self-monitoring and trait-based variance in leadership: An investigation of leader flexibility across multiple group situations. J. Appl. Psychol. 76, 308–315. doi:10.1037/0021-9010.76.2.308

Supplemental Figures

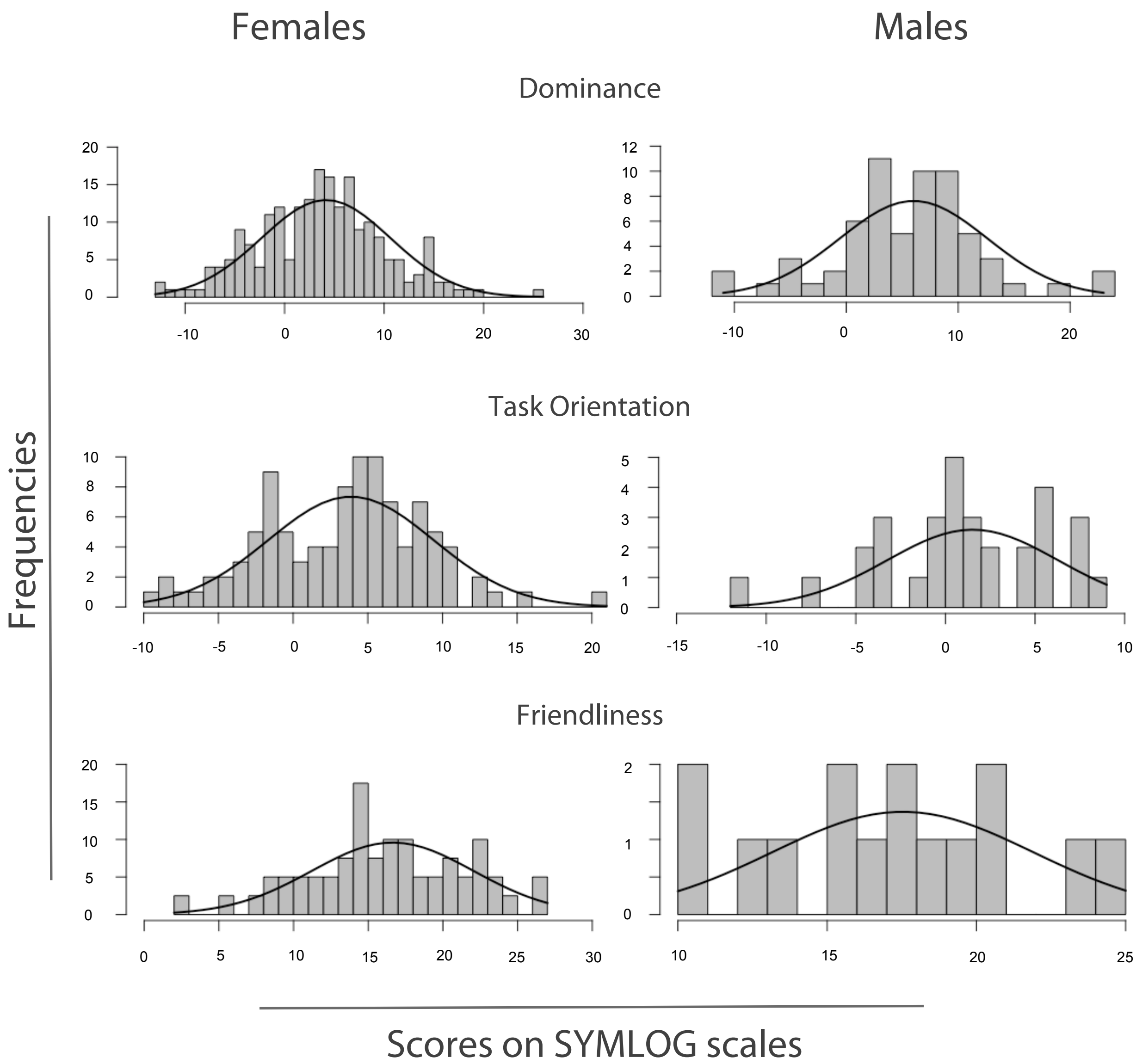

Figure S1: Distributions of the scores that the subjects of the participant pool obtained at each of the SYMLOG subscales (Dominance, Task Orientation, Friendliness), separately for female and male participants.