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Making Social Neuroscience Less WEIRD: Using fNIRS to Measure Neural Signatures of Persuasive Influence in a Middle East Participant Sample

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The large majority of social neuroscience research uses WEIRD populations—participants from Western, educated, industrialized, rich, and democratic locations. This makes it difficult to claim whether neuropsychological functions are universal or culture specific. In this study, we demonstrate one approach to addressing the imbalance by using portable neuroscience equipment in a study of persuasion conducted in Jordan with an Arabic-speaking sample. Participants were shown persuasive videos on various health and safety topics while their brain activity was measured using functional near infrared spectroscopy (fNIRS). Self-reported persuasiveness ratings for each video were then recorded. Consistent with previous research conducted with American subjects, this work found that activity in the dorsomedial and ventromedial prefrontal cortex predicted how persuasive participants found the videos and how much they intended to engage in the messages' endorsed behaviors. Further, activity in the left ventrolateral prefrontal cortex was associated with persuasiveness ratings, but only in participants for whom the message was personally relevant. Implications for these results on the understanding of the brain basis of persuasion and on future directions for neuroimaging in diverse populations are discussed.

Keywords: Arab, fNIRS, neuroimaging, persuasion, WEIRD

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Psychological and behavioral research has been conducted almost exclusively with WEIRD populations—Western, educated, industrialized, rich, and democratic (Henrich, Heine, & Norenzayan, 2010). Although 96% of participants in published behavioral research are from WEIRD countries, these countries only account for 12% of the world's population (Arnett, 2008). This is problematic given strong evidence in social, cognitive, and perceptual domains of differences between WEIRD and non-WEIRD populations (for reviews, see Ames & Fiske, 2010; Han, 2015; Han & Ma, 2014; Markus & Kitayama, 1991). In neuroscience as well, it is difficult to know whether findings are generalizable, or limited to the WEIRD samples that make up the majority of published findings (Falk, Hyde, et al., 2013). At the journal *Social Cognitive and Affective Neuroscience,* where there is a dedicated editor for cultural neuroscience, 76% of all article submissions in 2016 were from WEIRD countries. Submissions from East Asian countries accounted for 21% of submissions, with just 3% of submissions from Central and South America, South Asia, Africa, and the Middle East.

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Although the issue of representativeness can conceivably be reduced by fostering research capacity in diverse regions, as well as airline tickets and online crowd source platforms such as Mechanical Turk, the problem for neuroscience is harder to address because of the equipment needed for neuroimaging. Functional MRI (fMRI) has been the most common modality in functional neuroimaging over the past two decades, but is not widely available in much of the world nor suited for field work or travel. Typical MRI scanners weigh several tons and cost millions of dollars to purchase. These aspects of neuroimaging make it a serious investment for even large research institutions, and are impediments for many researchers wishing to increase participation of non-WEIRD populations in social and cognitive neuroscience, especially beyond research teams in cities and countries that have made large investments in MRI.

Recently, however, functional near infrared spectroscopy (fNIRS) has emerged as an alternative neuroimaging technique that has important advantages over fMRI in terms of increasing diversity in neuroscience. Specifically, fNIRS measures brain activity via propagation of infrared light through the cortex. Because oxygenated hemoglobin, a signal of brain activity, absorbs or scatters infrared light while skin and bone are relatively transparent to it, brain activity can be measured by projecting infrared light into the scalp and measuring the local concentration of hemoglobin (see Figure 1; for more information on the biophysics of fNIRS, see Ferrari & Quaresima, 2012, and Scholkmann et al., 2014). This use of optics instead of magnetics allows fNIRS equipment to be much smaller than fMRI, to the point where it can be packed into carry-on luggage on an airplane or otherwise transported to field locations. It is also more feasible to acquire, being an order of magnitude more affordable than fMRI and requiring no operational costs besides electricity and expertise. Although fNIRS is not as spatially resolved as fMRI and cannot collect data from deep brain structures (cingulate cortex, amygdala, ventral striatum, etc.), its advantages make it an important development for cultural neuroscience goals. In recent years, it has been a feature of both lab-based cross-cultural investigations (e.g., Murata, Park, Kovelman, Hu, & Kitayama, 2015; Yu, Pan, Ang, Guan, & Leamy, 2012) as well as the technology of choice for infant cognitive development research in rural Gambia (Lloyd-Fox et al., 2014, 2015) and Guinea-Bissau (Roberts et al., 2017).

In the current investigation, we aimed to use fNIRS for improving the generalizability of persuasion neuroscience, a social neuroscience subarea that is currently well established in WEIRD populations, but almost completely untested in non-WEIRD groups. This work finds that activity in the dorsomedial prefrontal cortex (dmPFC), tempoparietal junction, and other mentalizing network regions while viewing or reading persuasive messages correlates with ratings of persuasion and liking of the message and communicator (Falk, Morelli, Welborn, Dambacher, & Lieberman, 2013; Falk et al., 2010; Klucharev, Smidts, & Fernández, 2008; Ramsay, Yzer, Luciana, Vohs, & MacDonald, 2013; Weber, Huskey, Mangus, Westcott-Baker, & Turner, 2015). This is consistent with the idea that enhanced processing of the narrative of the message or its value to others may increase its perceived persuasiveness. In addition, regions involved in self-processes and personal valuation including the ventromedial prefrontal cortex (vmPFC) and ventral striatum predict personal behavior change in compliance with a persuasive message as well as other relevant outcomes such as message recall. This has been observed with smoking cessation (Dinh-Williams, Mendrek, Dumais, Bourque, & Potvin, 2014; Falk, Berkman, & Lieberman, 2012; Falk, Berkman, Whalen, & Lieberman, 2011; Falk et al., 2016; Wang, Lowen, Romer, Giorno, & Langleben, 2015), sunscreen use (Burns et al., 2018; Falk, Berkman, Mann, Harrison, & Lieberman, 2010; Vezich, Katzman, Ames, Falk, & Lieberman, 2017), physical exercise (Cooper, Bassett, & Falk, 2017; Falk et al., 2015), safe sexual practice (Wang et al., 2016), and idea propagation (Falk, O'Donnell, & Lieberman, 2012; Falk, Hyde, et al., 2013).

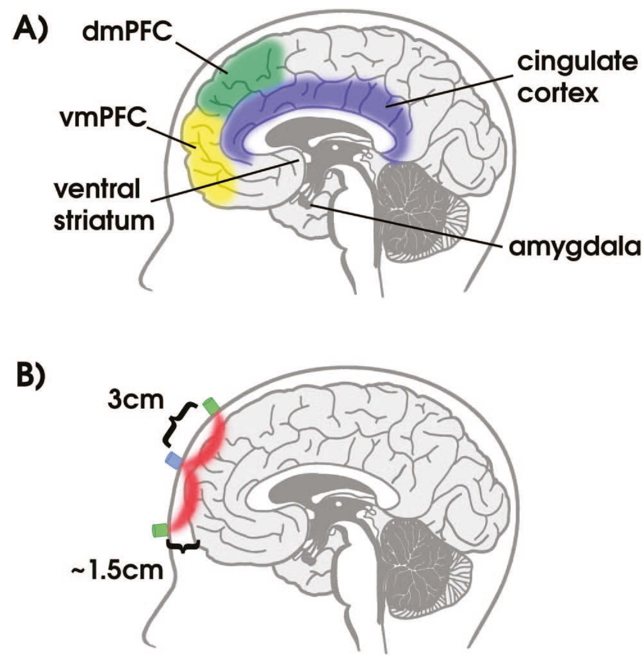

Figure 1. (A) Location of common brain areas of interest in social neuroscience research. (B) Depiction of fNIRS optodes positioned on the scalp, and the approximate path of infrared light traveling through the cortex underneath. The majority of the signal penetrates to a depth that is roughly half the distance of optode separation. Therefore a standard 3-cm optode separation will collect brain activation ~1.5 cm beneath the scalp. Deeper recordings up to a few more centimeters are possible, but at the cost of signal quality. It is currently not possible to record fNIRS signal from deep brain regions such as cingulate cortex, amygdala, or ventral striatum, but this may change in the future with fNIRS engineering advances. See the online article for the color version of this figure.

Many reports on prefrontal activity during persuasive messaging also identify how individual differences impact the relationship between brain activity and persuasion—namely, that the relationship is stronger when messages are personally tailored (Chua, Liberzon, Welsh, & Strecher, 2009; Chua et al., 2011), are presented to nonusers of a health behavior (Burns et al., 2018; Vezich et al., 2017), or are presented to audiences who are less likely to resist the messages (Huskey, Mangus, Turner, & Weber, 2017; Wang et al., 2016; Weber et al., 2015). Together these studies suggest that when a persuasive message is new to the receiver and that receiver is motivated to evaluate the message's content, the amount of neural activity that occurs during message viewing is indicative of persuasion outcomes. If a receiver has already processed the message before and either incorporated it into their behaviors or rejected it based on readily available counterarguments, mPFC activity is less predictive of downstream behavior and persuasiveness ratings.

Particularly interesting to applied research contexts, other results suggest that neuroimaging may be a valuable tool in program assessment where it is important to track the success or failure of persuasive messaging. Activation in the vmPFC while viewing persuasive messages can complement standard self-reports of persuasion, accounting for additional variance in poststudy behavioral compliance with the message (Falk et al., 2011). Collecting neural data from a small group can also predict population-level performance metrics for messaging campaigns (Falk et al., 2012, 2016; Genevsky & Knutson, 2015; Venkatraman et al., 2015). These results show that prefrontal and ventral striatum activation as a signature of persuasion are robust and replicable findings.

Although the majority of these investigations have been done with fMRI, we previously conducted a successful fNIRS study of persuasion, showing that the typical fMRI results can be replicated in the fNIRS modality. In Burns et al. (2018), American participants' brain activity was measured with fNIRS while they read persuasive messages about sunscreen (e.g., "daily sunscreen use will keep your skin looking younger" or "lack of sunscreen increases your risk for skin cancer"). The number of times they used sunscreen in the following week was then measured. The results showed that there was a significant association between the amount of activity in vmPFC while viewing the persuasive messages and how often participants used sunscreen postscan, replicating previous work. This relationship was also stronger in participants who were not already using sunscreen. The effect sizes were similar to other fMRI studies as well (e.g., Falk et al., 2011; Vezich et al., 2017).

The body of literature on persuasion neuroscience is consistent and well established, but so far it consists almost entirely of WEIRD participant samples from the United States, Canada, and Western Europe. Of note, one study thus far has examined the neural bases of persuasion in a non-WEIRD sample. Falk et al. (2010) recruited both European American participants and Korean-born participants living in the United States for an fMRI study that measured neural activation while participants viewed persuasive text arguments about a variety of objects and activities. The resulting analysis showed that European American and Korean participants activated the same set of brain regions for messages they rated as persuasive: the dmPFC, bilateral posterior superior temporal sulcus, bilateral temporal pole, bilateral medial temporal lobe, and left ventrolateral prefrontal cortex (vlPFC). This provides some initial evidence that medial prefrontal activity might indicate a broad marker of persuasiveness beyond WEIRD samples, but there were some limitations to this study. First, this investigation only included European Americans participants and Korean participants living in the United States, so the results cannot be extended to all cultural groups. Second, the Korean sample consisted of individuals living in the United States, a group that might differ in important ways from a sample that lived in Korea and were not living with bicultural influences.

For this study, then, we aimed to extend the investigation of the generalizability of persuasion neuroscience and replicate the relationship between medial prefrontal neural activity and persuasion in a native Arabic-speaking sample recruited in Amman, Jordan. To our knowledge, this is the first social neuroscience investigation performed with a native Arab population. This is a group that is also understudied in psychology more generally, especially in basic social psychological research. Relevant to the study of interpersonal influence and persuasive messaging, a small literature suggests that Arab societies in the Middle East foster a more collectivist than individualist self-construal, similar to East Asian populations that are more prevalent in the cultural psychology literature (Dwairy, Achoui, Abouserie, & Farah, 2006; Hofstede, 1983). Arab participants' individual personality factors as measured using standard Western instruments are less predictive of behaviors than social norms, values, and familial roles (Dwairy, 2002), which may be a result of stronger cultural emphasis on interdependence or collectivism. Further, communication patterns emphasize group bonding and maintenance more so than individual enhancement, which is more common in Western societies (Feghali, 1997; Taher, Kazarian, & Martin, 2008). However, other research suggests some Arab societies highly emphasize both collectivist and individualist values as independent, context-sensitive phenomena (Dwairy, 2004b; Oyserman, 1993), and there is great variation within countries between urban Arabs with more multicultural contact and rural Bedouin groups (Dwairy, 2004a). There may also be other cultural differences in social values and cognitive styles between Arab societies and WEIRD groups that are less-commonly discussed, such as social hierarchy endorsement and uncertainty avoidance (Hofstede, 1983), or the kinds of social relationships that collectivist self-construals are based on (Harb & Smith, 2008). Most recently, San Martin et al. (2018) found that Middle Eastern Arab samples were as interdependent as East Asians, but displayed self-assertive tendencies that are more typical of independent cultures if in the service of the group. So it is not immediately clear how well neural indicators of persuasion in WEIRD samples, which correspond to regions that code for social and personal evaluation, will map onto native Arab subjects.

Thus, we tested several hypotheses from the existing persuasion neuroscience literature in this investigation. First, we tested whether dmPFC and vmPFC activity is related to persuasion in this non-WEIRD sample, both in terms of the self-report of persuasiveness and of intent to engage in the behavior endorsed by a message. We also tested other measures of message self-relevance such as message agreement, message identification, and whether different levels of message targeting affected the relationship between brain activity and persuasiveness rating. Finally, we investigated how well average neural activity in this participant sample predicts the group's average ranking of the different messages' persuasiveness, to identify which messages were the most effective overall. In this way, the current investigation tests whether or not the psychological processing of persuasive messages is consistent across participants from different cultures.

Method

Participants

Participants were male adults from Amman, Jordan (age M = 29.59 years, SD = 9.30). All were Arabic speakers and gave informed consent to participate in Arabic. Forty-one participants were recruited. Eleven were smokers with children, nine were nonsmokers with children, 13 were smokers with no children, and eight were nonsmokers with no children. Recruitment was conducted via phone invitation to participate in a separate video marketing study, after which the authors obtained the data for analysis for the purpose of this paper. Sample size was determined by the greatest possible number of participants that could be scanned in a limited amount of time available in Amman, not via a power planning procedure. However, a hypothetical a priori power analysis based on the reported effect sizes found in previous neuroscience work on neural mechanisms of self-reported persuasion reveals that a sample size of 29 would have been suggested for 80% power at α = .05. The effective sample sizes in the multilevel models reported below depended on the intraclass correlations (ICC) within the models—for example, if brain activity across videos or participants is positively correlated, then there would be effectively less unique information, or fewer effective observations contributing degrees of freedom to that test than if all video presentations to all participants were completely independent (Peckham, Glass, & Hopkins, 1969). When the ICC for each model is calculated, a design effect attributable to data clustering can be derived as *design effect* = *1* + (*group size* – 1) * ICC. This describes by how much a sample size should be increased to maintain equal power when accounting for group homogeneity (Kish, 1965). Thus dividing the true study sample size by this design effect yields effective sample size. The effective sample size in all of these models ranged from 32.26 to 61.70, suggesting that there is adequate expected power.

Materials

Imaging technology. This project relied on fNIRS as a neuroimaging alternative to fMRI. Specifically, a NIRSport imaging unit from NIRx was used (nirx.net/nirsport) because of its compact size and portability. This unit has eight light sources and eight light detectors, which were positioned to create 20 channels of data. Because of the limited spatial coverage of this layout, and the fact that fNIRS cannot image deep brain structures, we chose to focus on only scanning the dorsolateral and medial prefrontal cortical areas of the brain and to replicate previous persuasion neuroscience findings concerning these areas. These areas are also several centimeters in size, well within the fNIRS spatial resolution margin of about 1 cm. Four elastic head caps of different sizes were used to affix the light sources and detectors to participants' heads depending on their head size. Spatial positioning was standardized over all participants using the 10–10 UI external positioning system. Light intensity data were collected at wavelengths of 760 and 850 nm and sampling rate of 7.81Hz.

Experimental items. Nine video commercials were used as the persuasive messages in this study. All videos were in Arabic and had previously aired as public health and safety advertisements on Jordanian or Egyptian TV in the past. Two of the videos discouraged smoking, five encouraged the use of contraception for family planning, and two discouraged support for violence (specifically *D'aesh*, the Arabic term for the group known in the West as ISIS). The videos were between 47 and 180 seconds long. Because of the necessity of using persuasive messages with culturally specific content presented in Arabic, these exact materials have not been used in previous persuasion neuroscience studies. However, they more generally replicate previous approaches of using public health videos that have been previously aired on TV (e.g., Falk et al., 2012; Ramsay et al., 2013; Weber et al., 2015).

Participants completed a survey about their demographics, including whether or not they smoked and whether or not they had children. This survey also asked baseline measures of their opinions on smoking and family planning practices. Baseline attitudes about violence were not assessed. After each video participants also answered survey questions on various measures of the effect of the persuasive messages: (a) how much they agreed with the video's message (*Agreement*); (b) how much they thought the video was made for people like them (*Identification*); (c) how persuasive they thought the video would be to others (*Perceived Effectiveness*); and (d) how much they intended to follow the behavior promoted by the video (*Behavioral Intent*). These measures are conceptually related, but different persuasion neuroscience studies focus on different persuasion definitions, so we have included several common self-report measures of persuasion. The questions were answered via a Likert scale ranging from 1 to 7. These materials were all provided to participants in Arabic (see online supplemental materials).

Procedure

The experiment was conducted over the course of one week. When participants arrived, an Arabic-speaking experimenter administered consent. Afterward, participants were fitted with the fNIRS cap and the signal was calibrated. All effort was made to ensure good scalp contact and signal quality was achieved, and room lighting was dimmed to limit ambient optical noise.

At the start of the experiment, participants completed the baseline questionnaire. Then, participants watched the smoking videos in randomized order, then the family planning videos randomized, and finally the antiviolence videos randomized. After watching each video, they completed the measures on Agreement, Identification, Perceived Effectiveness, and Behavioral Intent for that specific video. An Arabic-speaking experimenter was in the room with the participant to start videos, administer the questionnaires, and answer clarifying questions if necessary. Participant brain activity was recorded while they watched the videos.

Neural Data Preprocessing

Data collected with fNIRS was preprocessed using Homer2. To determine data quality, the raw time courses were first inspected for clear heartbeat signal and a 1/*f* power spectral density shape. If too much noise was present in a data channel, that specific channel was marked as unusable and removed from analysis. Several participants had one or two channels removed in this way. If any participant had more than 50% of their data channels removed, that entire subject was discarded from analysis. Five subjects were removed for this reason, leaving 36 participants' data for analysis. The data were then bandpass filtered to 0.005–0.5 Hz to exclude machine signal drift. A PCA algorithm was also used to identify and remove spike artifacts in the data attributable to optode motion. Light intensity values were then converted to percent change in oxygenated hemoglobin concentration relative to the entire scan baseline, using the Modified Beer Lambert Law.

Typical analysis of hemodynamic brain activity fits a canonical hemodynamic response function (HRF) to the data before testing it against a design matrix in order to calculate amount of neural activity. However, canonical HRFs do not fit well to neural responses to long stimuli because they scale nonlinearly (Glover, 1999), which is of concern here because of the lengths of the videos used in this study. Therefore an average percent change in oxygenated hemoglobin concentration was calculated over the course of each video instead, minus the first and last five seconds. This is similar to the percent signal change method in fMRI analysis. Dependency between video length and average activation was checked, but was not significant.

For spatial localization and visualization of the results, the corresponding MNI coordinates of each 10–10 UI external channel position was determined using a probabilistic conversion atlas (Figure 2; http://www.jichi.ac.jp/brainlab/tools.html). Statistical results were calculated for each channel, and then linear interpolation was used to smooth the statistical maps between each channel's MNI location. Images were generated by converting NIRS results to .img/.hdr files using xjview (http://www.alivelearn.net/xjview/), which were then loaded into the Surf Ice brain surface rendering software.

Statistical Analysis

For the analyses linking persuasion measures to brain activity, cross-classified multilevel models grouped by participant and video were run on the data to determine whether a participant's average brain response while watching a video was significantly related to any of their answers on the self-report persuasion measures (Agreement, Identification, Perceived Effectiveness, or Behavioral Intent). One multilevel analysis was run for each outcome variable and each neural data channel. The Satterthwaite method was used to calculate degrees of freedom, and results were corrected for multiple comparisons across all neural data channels using the false discovery rate approach (FDR). Effect sizes are reported as the marginal R^2 (variance explained by the fixed effect) from Nakagawa and Schielzeth (2013).

To see how message targeting affected the relationship between neural activity and persuasiveness ratings, each video was ideographically labeled as "targeted" or "nontargeted," depending on whether there was a match with a personal characteristic of the participant. For instance, if a smoker saw an antismoking ad, that ad was labeled a targeted video while the same video for a nonsmoker was labeled as nontargeted. Likewise, family planning videos (which contained information about spacing pregnancies) were labeled targeted if the participant had children, and were labeled nontargeted if they did not have children. Antiviolence videos were left out of this analysis because there was no demographic variable relevant to this topic. Similar multilevel models to the aforementioned analyses were then run, this time investigating the main effect of targeting as well as the interaction with the persuasion measures.

Finally, we also analyzed the data at the group level to investigate whether aggregated brain activity was predictive of each message's average Behavioral Intent. In applied research and messaging program development, it would be worthwhile to know whether a simple metric like average brain activity from a small group of subjects can be used in a brain-as-predictor approach (Berkman & Falk, 2013) to find the most effective messages for a wider population, rather than just predictive of individuals' preferences as the previous analyses investigate. To do this, we computed an average brain response value across all participants in each neural data channel for each of the nine videos and ran a linear regression on the mean persuasiveness ratings for each of those videos. Results were FDR-corrected.

Because this test has very limited statistical power (there were just nine data points corresponding to the group-averaged brain activity in each video, instead of all video presentations in all subjects), we also ran a bootstrapping procedure to generate 10,000 random samples of the participants' brain data (selected with replacement). Across all these samples, we measured how frequently the video rankings as determined by average brain activity matched the real consensus Behavioral Intent rankings. We repeated this at every sample size n up to and including the study sample size because it is relevant to know how big of a sample size is necessary for accurate population estimation in studies with applied research goals or difficult-to-recruit populations.

Results

Relationship Between Individual Brain Activity and Persuasion Measures

Perceived Effectiveness ratings significantly predicted multiple prefrontal areas (Table 1 and Figure 3). Peak correlation was in the right dmPFC, $t(285) = 3.98$, $p < .001$, marginal $R^2 = 0.13$ and left vlPFC, $t(256) = 3.69$, $p < .001$, $R^2 = 0.05$. Effective sample sizes in these tests were 61.70 and 32.46, respectively. Identification also predicted activity in the right dmPFC (Figure 3), $t(282) =$

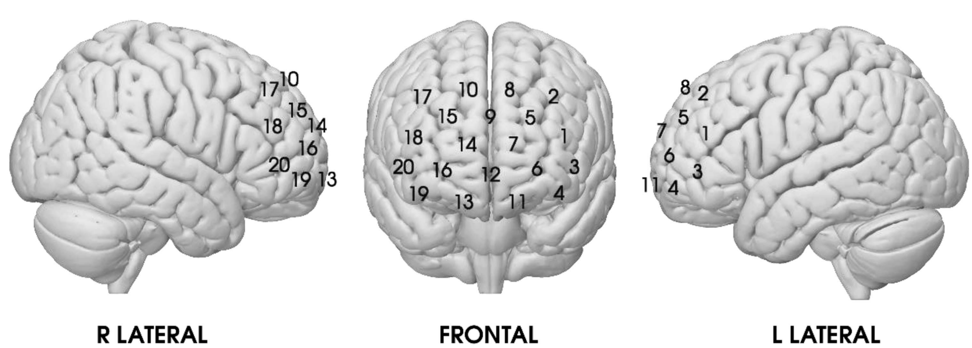

Figure 2. Spatial location of fNIRS neural data channels, projected onto the prefrontal cortex surface.

Table 1
Prefrontal Areas Significantly Associated With Perceived Effectiveness of Persuasive Messages

Prefrontal subarea	Approx. MNI coordinate	T statistic	P value
Left dorsolateral (ch5)	−24, 55, 31	3.36	<.001***
Right dorsolateral (ch15)	26, 55, 31	2.32	.021*
Right dorsolateral (ch17)	32, 43, 40	2.59	.010*
Left ventrolateral (ch3)	−46, 48, 0	3.69	<.001***
Right ventrolateral (ch19)	35, 63, −8	2.28	.024*
Dorsomedial (ch9)	2, 54, 38	2.50	.013*
Left dorsomedial (ch8)	−10, 44, 48	2.79	.0056**
Right dorsomedial (ch10)	12, 44, 48	3.98	<.001***
Medial (ch12)	3, 66, 11	3.09	.0022**
Left Medial (ch7)	−24, 65, 21	2.51	.013*

* $p < .05$. ** $p < .01$. *** $p < .001$.

3.12, $p = .002$, marginal $R^2 = 0.09$. Effective sample was 59.84. Neither Agreement nor Behavioral Intent were found as significant predictors of brain activation, however the relationship between Behavioral Intent and vmPFC was marginal for these individual level models. Perceived Effectiveness and Behavioral Intent are significantly associated with vmPFC activity in models where subject is the sole random effect, instead of both subject and video. Both the left and right vmPFC were associated with Perceived Effectiveness in this way (left: $t[306] = 2.46$, $p = .015$; right: $t[286] = 2.65$, $p = .0084$), and the right vmPFC was associated with Behavioral Intent, $t(301) = 2.87$, $p = .0045$. This suggests that vmPFC effects are attributable to between-video differences - within the same video, persuasion ratings did not predict vmPFC activity, but the average vmPFC activity in each video corresponded to the average persuasion ratings in each video.

Effect of Message Targeting

No main effect of targeting was identified, such that there was no difference in activation in any brain area between targeted and nontargeted videos. However, as seen in Figure 4, a significant interaction was found between targeting and Perceived Effectiveness in the right dmPFC, $t(224) = -3.19$, $p = .0016$, effective $n = 45.75$, and the left anterior superior frontal sulcus (aSFS), $t(221) = -4.49$, $p < .001$, effective $n = 32.26$. Analysis of simple effects showed that in nontargeted videos only, there was a significant association between Perceived Effectiveness and activity in the right dmPFC, $t(78.4) = 3.34$, $p = .0013$, $R^2 = 0.32$, and left aSFS, $t(104) = 4.52$, $p < .001$, $R^2 = 0.20$. Although targeted videos had a significant association in the left vlPFC, the interaction in this area was not significant. This suggests that the relationship between Perceived Effectiveness and brain activity in medial prefrontal areas is dependent on whether or not the message is personally relevant to the participant.

Identifying the Most Persuasive Messages From Average Brain Activity

Results from the linear regression between aggregated brain and persuasion data indicate that there is a significant relationship between average brain activity across participants and average Behavioral Intent in the left vmPFC, $t(7) = 4.69$, $p = .0022$, $R^2 = 0.72$ (Figure 5). This is in agreement with the previous vmPFC results mentioned.

Table 2 and Figure 6 show the results from the bootstrapping test that measures how accurately aggregated brain data from samples of varying sizes predict which videos elicited the most average behavioral intent in the study population. Specifically, they report the accuracy scores at each sample size for predicting (a) which videos were in the top, middle, and bottom tiers of Behavioral Intent rank, (b) the top three videos in terms of Behavior Intent rank, and (c) what the top video was overall. At every sample size, these subsamples were better than chance at predicting real video ranking. The brain data reached 52.58% accuracy of predicting video tiers, 96.03% accuracy of predicting the top three videos, and 75.14% accuracy of predicting the top video overall. A

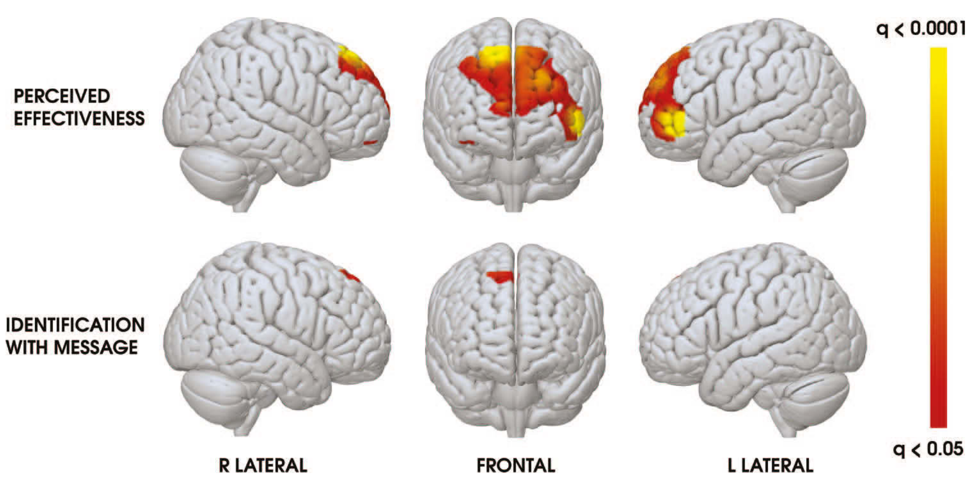

Figure 3. Prefrontal cortex areas that were significantly associated with Perceived Effectiveness of the message (top row) and Identification with the message (bottom row). Results were FDR-corrected to $q < 0.05$. The strongest associations with Perceived Effectiveness were found in the right dmPFC, $t(285) = 3.98$, $p < .001$, $R^2 = 0.13$, and left vlPFC, $t(256) = 3.69$, $p < .001$, $R^2 = 0.05$. Right dmPFC was also significantly associated with Identification with the message, $t(282) = 3.12$, $p = .0020$, $R^2 = 0.09$. See the online article for the color version of this figure.

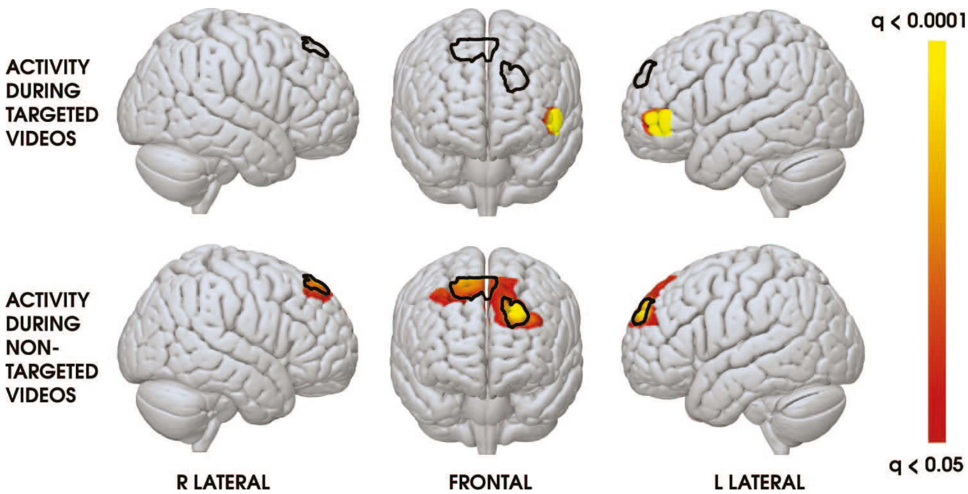

Figure 4. Areas of significant association between brain activity and Perceived Effectiveness during viewing of targeted videos (top row) and nontargeted videos (bottom row). Statistically significant interactions between video targeting and Perceived Effectiveness were found in the areas outlined in black. Analysis of simple effects showed that there was a significant association between Perceived Effectiveness and activity in the right dmPFC, $t(78.4) = 3.34$, $p = .0013$, $R^2 = 0.32$, and left aSFS, $t(104) = 4.52$, $p < .001$, $R^2 = 0.20$, during nontargeted videos, but not targeted videos. Although targeted videos had a significant association in the left vlPFC, the interaction in this area was not significant. See the online article for the color version of this figure.

sample size of seven was enough to provide the correct answer more often than not for the last two metrics.

Discussion

People from Western, educated, industrialized, rich, and democratic (WEIRD) populations make up a minority of the world's total population, but a large majority of the subjects used in psychological research (Arnett, 2008; Henrich et al., 2010). In neuroscience specifically, the disparity is largely attributable to the expense and size of traditional neuroimaging technology. However, the development of fNIRS—an alternative neuroimaging modality that is less expensive and more portable than fMRI—has made it easier to conduct field research and improve participant diversity. Here, we conducted a study on the neural correlates of persuasion in a native Arab sample in Amman, Jordan to investigate potential similarities and differences in neural mechanisms of persuasion across cultures.

The results show persuasiveness of messages was related to neural activity in this Middle Eastern sample in brain areas matching the spatial locations observed in Western samples. Specifically, activity in the dmPFC was positively associated with ratings of perceived message effectiveness and message identification for the videos shown in this study. This parallels the results from Klucharev et al. (2008) and Falk, Morelli, et al., (2013), where activity in the dmPFC while viewing advertisements for various objects or behaviors was associated with how persuasive subjects thought those advertisements were. Likewise, Falk et al. (2010) found that the dmPFC was more active for text passages rated as persuasive versus passages rated as unpersuasive, in both European American and Korean participants. Thus, the results of this study add greater confidence that the dmPFC is a correlate of perceptions of persuasiveness across diverse populations.

When the relationship between persuasion ratings and brain activity was investigated as a function of message targeting, we found that this relationship was stronger in the dmPFC and left aSFS for nontargeted videos than for targeted. In other words, brain activity in these medial prefrontal areas tracked more closely to perceived effectiveness ratings when nonsmokers were watching antismoking ads and when participants with no children were watching family planning videos than when smokers and parents watched the same videos. This is in agreement with other studies that investigated neural correlates of persuasion based on issue involvement, such as users and nonusers of sunscreen reading about why sunscreen is important (Burns et al., 2018; Vezich et al., 2017). In those studies, medial prefrontal cortical activity is only positively associated with persuasion in low-involvement participants. Speculatively, this may be because high-involvement participants have already evaluated and weighed the value of this information, and so are using other mechanisms (such as memory for preexisting opinion) to decide message persuasiveness besides mPFC indexing of personal and social value.

Average activity in the left vmPFC at the group level was also found to predict the average behavioral intentions for each advertisement. This is consistent with work finding that average neural activation in this region across a small group of participants predicts group level (Doré et al., 2018) and population-wide behavioral patterns (Falk et al., 2012; Falk et al., 2016). This again suggests that this pattern may be consistent across cultural groups, and thus may apply in other scenarios across the globe where predicting the future success of a persuasive message is important.

However, it is worth noting that this vmPFC result was only found for the group consensus value of the messages (i.e., when neural activity and survey responses were averaged across the participant group for each video), and not when individual partic-

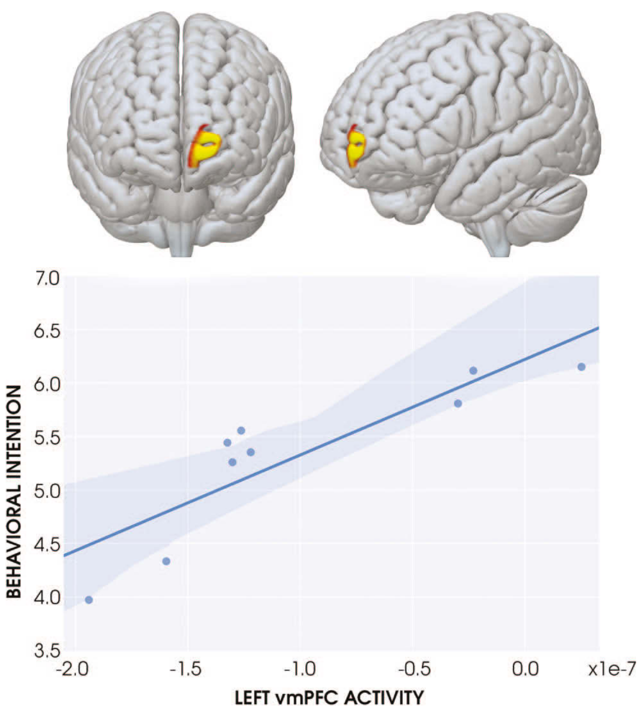

Figure 5. Graph of average Behavioral Intention plotted against average left vmPFC activity (change in molar concentration of oxygenated hemoglobin) for every video in the study. The correlation is $r = .87$. See the online article for the color version of this figure.

ipants were treated as the level of analysis in cross-classified multilevel models. This may be because persuasion research normally tracks not just the self-report of behavioral intention, but actual behavioral change after the experiment (e.g., expired CO2 concentration for smokers, days sunscreen used, etc.). Self-report of behavioral intentions is related, but not synonymous with downstream behavior (Webb & Sheeran, 2006), so it may be the case that the focus on self-reported behavioral intention obscured the vmPFC-persuasion relationship at the individual level and could only be detected at the group level. For this particular study, it was not feasible for the research team to collect behavioral data several days after the experiment, but future work should add this component to determine whether vmPFC activity truly does predict behavior change across cultural groups.

Alternatively, this difference may be attributable to cultural variation between this Arab sample and the WEIRD samples in previous persuasion neuroscience studies. There is a well-documented difference between WEIRD and non-WEIRD samples in terms of their self-construal being more individualist, as one among others, or collectivist, as a part of others (e.g., Markus & Kitayama, 1991). At the neurological level, the vmPFC and dmPFC seem to index self-relevant and other-oriented thought, respectively, in both Western and East Asian participants (Kobayashi, Glover, & Temple, 2006; Zhang et al., 2006). But across cross-cultural studies of self and social processes, East Asians tend to recruit the dmPFC more for this cognition than Western participants, and the vmPFC is recruited more in Western participants (Han & Ma, 2014). The psychological consequences of these findings may be that when making socially relevant judgments, individualist society members engage in more self-relevant valuation, whereas collectivist society members consider information more from the perspective of what is valuable to one's larger group (Tompson, Lieberman, & Falk, 2015). Although it is still unclear whether Arab samples have a similar neurocognitive profile to East Asian participants, the lack of individual-level vmPFC results may suggest that they are evaluating messages more in terms of what is valuable to their family and community, rather than just what is valuable to their own person. This is especially possible considering that the video stimuli were about behaviors that directly impact close social relationships—smoking, family planning, and political violence. Now that this possible cultural difference has been identified, future work could test for it more directly.

Finally, it is worth noting a more general takeaway about the fNIRS method used in this study. For future field-based neuroscience to be successful, evaluation of the data quality from portable neuroimaging should be explicit. In our study, only a handful of subjects were removed from analysis because of bad data quality—comparable with the number often removed from fMRI or EEG experiments for data issues such as excessive participant motion. It was also much faster and more financially feasible to recruit and scan participants with this fNIRS unit than is typical in an fMRI experiment. The portability of fNIRS is also valuable for cultural neuroscience goals. However, the fNIRS modality is inherently

Table 2
Accuracy of Predicting Group Video Rankings From Left vmPFC Activity at Various Sample Sizes

	Predicting top, middle, and bottom video tiers		Predicting top three videos		Predicting top video	
Sample size	Brain	Chance	Brain	Chance	Brain	Chance
n = 1	5.65% (± .24%)[a]	.06% (± .03%)	20.51% (± .41%)	1.16% (± .11%)	20.61% (± .41%)	11.72% (± .31%)
n = 5	9.17% (± .29%)	.09% (± .03%)	40.70% (± .49%)	1.16% (± .11%)	48.92% (± .50%)	11.65% (± .30%)
n = 10	18.39% (± .39%)	.11% (± .02%)	62.53% (± .48%)	1.18% (± .10%)	59.22% (± .49%)	10.99% (± .31%)
n = 15	28.08% (± .45%)	.09% (± .03%)	76.59% (± .42%)	1.15% (± .11%)	64.83% (± .48%)	11.24% (± .32%)
n = 20	36.18% (± .48%)	.07% (± .02%)	84.88% (± .36%)	1.31% (± .12%)	69.01% (± .47%)	10.80% (± .31%)
n = 25	42.50% (± .49%)	.11% (± .03%)	90.08% (± .29%)	1.15% (± .11%)	70.99% (± .45%)	11.01% (± .32%)
n = 30	48.73% (± .50%)	.08% (± .02%)	93.86% (± .24%)	1.19% (± .11%)	74.72% (± .44%)	11.18% (± .31%)
n = 34[b]	52.58% (± .50%)	.12% (± .03%)	96.03% (± .20%)	1.34% (± .10%)	75.14% (± .43%)	10.98% (± .32%)

[a] 95% confidence intervals reported next to accuracy estimate. [b] Sample size only increased to 34 here, as two of the 36 total subjects did not have good data quality in the left vmPFC channel.

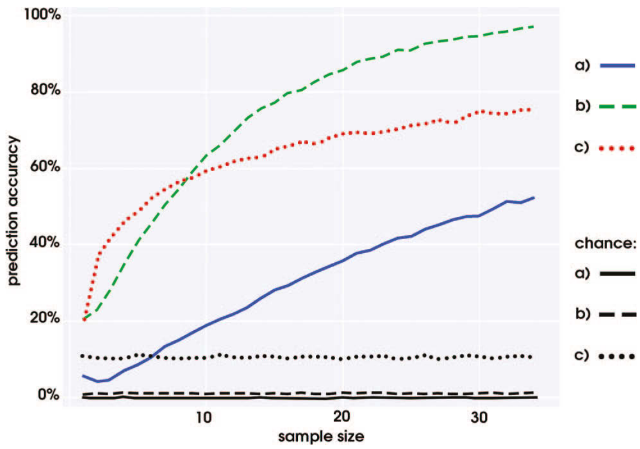

Figure 6. Accuracy of predicting group video ranking metrics, as sorted by self-reported Behavioral Intent, from neural data in left vmPFC for all sample sizes. (A) Accuracy of predicting which videos were in the most-persuasive, somewhat-persuasive, and least-persuasive tiers. (B) Accuracy of predicting the top three most effective videos. (C) Accuracy of predicting the top video overall. Corresponding chance rates for each metric shown in black. Accuracy estimates determined with a 10,000-iteration bootstrap procedure. 95% confidence intervals are too narrow to graphically represent here but are provided in Table 2. All neural prediction accuracy metrics at every sample size are significantly greater than chance. See the online article for the color version of this figure.

limited by its spatial resolution compared with fMRI—the fNIRS signal can be resolved only to about a centimeter (Cui, Bray, Bryant, Glover, & Reiss, 2011). Also, it cannot measure brain activity at a depth greater than a couple centimeters into the cortex at this stage in the method's development (Okada et al., 1997; Takahashi et al., 2011). This means that subcortical regions (e.g., amygdala, ventral striatum, basal ganglia), cortical regions in deep fissures (e.g., cingulate cortex, insula), or cortical regions on the underside of the brain (e.g., orbitofrontal cortex, fusiform face area) are not currently accessible to imaging with fNIRS given the present state of the technology. Our study focused on neural areas of interest (dmPFC, vmPFC, etc.) that are fairly large and include the surface of the cortex, so are thus not impacted by these constraints. Other large surface areas such as the sensorimotor cortex, tempoparietal junction, or temporal gyri would also be amenable to fNIRS imaging. Researchers considering the use of fNIRS should keep these tradeoffs in mind when designing future studies.

In conclusion, social neuroscience will continue to be WEIRD for some time, but new technology is available to begin to address the disparity. Using fNIRS, we conducted what is to our knowledge the first social neuroscience study performed in the Middle East. The results of this study are largely consistent with those seen in previous neuroimaging studies of persuasion in Western populations, and demonstrate the feasibility of using fNIRS for remote neuroscience research. Hopefully, this study will encourage a less WEIRD social neuroscience to flourish. If we can start to think of and treat social neuroscience as an area where true field work is possible, where scientists can work wherever the action is, then we are bound to end up with a richer, more diverse, and more ecologically valid social neuroscience in the near future.

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