Anomaly Detection Analysis

Our primary results for the Anomaly Detection analysis focus on directional chiefdom pairs with at least 1,000 cumulative trips (n=523). Very similar results were generated by reducing this restriction to only 100 cumulative trips over the 103 days (n=1,234)(Figure S5). Returning to the 1,000-trip minimum, results were also qualitatively unchanged when excluding 87 trips beginning or ending in Freetown (n=436)(Figure S6). To ensure that the lockdown anomalies did not substantially affect the latter number of anomalies observed, we repeated the analysis beginning March 30, 2015 (Figure S7). We find very few anomalies are detected relative to the 523 pairs assessed.

Time Series Analysis

The flexible family of ARIMA models allows for periodicity as well as long-term trends (i.e., non-stationarity). The parameters of an ARIMA model are typically defined as (*p,d,q*), where *p* is the order of autoregression, *d* is the number of differences needed to achieve stationarity, and *q* is the order of moving average terms.(1)

We used the *auto.arima* R function in the R package *forecast* to identify a range of (*p,d,q*) parameters to consider for the $N_{i,t}$ function.(2) We found that the maximum likelihood set of (*p,d,*q) for each panel was ≤2 for *p* and *q* and ≤1 for *d* in 94.6% of chiefdom pairs. Next we calculated for each panel the AIC of each combination (*p,d,q*) in this range. Calculating the mean AIC across panels, we found very poor support for $d>0$, therefore confirming visual inspections that the time series are stationary within the 103 days of data available. The highest level of support was found for (*p,d,q*) equal to (1,0,2), (1,0,1), and (2,0,2). The parameters ($p=1$, $d=0$, $q=2$) were used to generate the main results and we repeated our analyses with each other combination of *p* and *q* between 0 and 2.

Our primary mixed-effects time series model utilizes an ARIMA correlation structure of (1, 0, 2)(Table 1). Incidence is measured as the cumulative number of cases in the source and destination chiefdoms divided by the total population in those chiefdoms, and is shown to be both an independent predictor of lower travel ($p=0.0081$) and an important effect modifier of the lockdown magnitude. We measure no increase in travel to compensate for the lockdown, but instead a slight 3-5% decrease in travel ($P < 0.05$).

With its large population size, key economic and political role, and high density of towers, Freetown is expected to strongly influence the observed travel patterns. The results were qualitatively unchanged after excluding all trips originating from, or leading to, Freetown (Table S3).

Our primary results define trips as the change in location for an individual from day *t*-1 to day *t*. We relaxed this assumption to allow individuals to carry-forward their location such that an individual who had no recorded phone activity on day *t*-1 can record a trip on day *t* if they had a different location on day *t*-2 and again for *t*-3 (Table S4).

Our primary results utilize a correlation structure according to an ARIMA(1,0,2) model, but parameters (1,0,1) received similarly strong support across panels and generated similar results (Table S5).

Crossover Analysis

To convert to square kilometers, each unit of longitude and latitude at this location is approximately 110 km. Therefore, a square spanning one unit of latitude and one unit of longitude represents approximately $(110 \text{ km})^2 = 12{,}100$ square-km

Using an unmatched crossover analysis instead of the matched analysis presented in the main text, we measured the number of users who placed all calls within a 10 km radius during a control or intervention period. Only users with at least 2 calls placed in each period were eligible, because stationarity is impossible to assess using only one calling event. We show that the fraction of subscribers who are stationary during the intervention period is significantly higher than during the control periods (Table S6). Furthermore, the mean distance traveled, measured by either the total inter-tower distance or the convex hull area, showed between 3-fold and 11-fold differences between the intervention and control periods.

To assess the sensitivity of these results to the choice of a 10 km buffer around towers, we repeated this analysis using a 3 km buffer and again with no buffer. The results are qualitatively similar, with the 10 km buffer generating the most conservative odds ratio (OR) estimates, which we expect because small travel distances are unobserved and therefore any changes in them due to the intervention are also unobserved (Table S7).

The number of calling events was significantly lower during the lockdown. In order to assess if the change in stationarity was a result of decreased calling activity, we down-sampled calls during the control periods to match the number of calls during the intervention. The results were essentially preserved (Table S8), and again when the number of calls during control periods were down-sampled 50% further and yielded similar results.

In order to document changes in location within the intervention or control periods, subscribers must record at least two calling events. In order to test the sensitivity of our results to the cutoff of ≥2 events, we show that the findings are similar when the restriction increases to at least 5, or 10, events (Table S9).

We used Spearman rank correlation tests to non-parametrically assess a possible association between the percent reductions in distance traveled during the intervention periods as compared to the control periods. We measured a significant, positive coefficient comparing the size of the impact to the log-transformed chiefdom population size in the home location given to each subscriber based on their most-used tower (Figure S8). Nearly identical results were observed when comparing the intervention period to the control period on the following weekend (Spearman's rho = 0.30 [95% CI: 0.09, 0.49]). Freetown, the capital and largest city, is more than twice as populous as the next biggest chiefdoms. We repeated our analyses after removing this outlier and found the positive correlation was reduced, but still significant for both the pre- and post- control periods (Spearman's rho = 0.24 [0.02, 0.44] and 0.23 [0.02, 0.43], respectively).

Supporting Tables

Table S1. Paired T-Tests of differences in each individual's inter-tower distance traveled during each time period.

	Intervention versus Control (Pre-)		Intervention versus Control (Post-)		Control (Pre-) versus Control (Post-)	
	Mean Diff	**95% CI**	**Mean Diff**	**95% CI**	**Mean Diff**	**95% CI**
All Subscribers	-9.15 km	-9.27, -9.02	-9.16 km	-9.30, -9.03	-0.68 km	-0.82, -0.53
Mobile in at least 1 period	-46.95 km	-47.54, -46.36	-46.26 km	-46.89, -45.64	-2.64 km	-3.20, -2.08
Mobile in both periods	-18.10 km	-19.52, -16.67	-17.09 km	-18.57, -15.61	-1.82 km*	-2.85, -0.80

* $P = 0.0005$. For all other tests, $P < 0.0001$.

"Intervention Period" is March 27-29; "Control (Pre-)" is March 20-22; "Control (Post-) is April 3-5.

Table S2. Paired T-Tests of differences in each individual's convex-hull distance traveled during each time period.

	Intervention versus Control (Pre-)		Intervention versus Control (Post-)		Control (Pre-) versus Control (Post-)	
	Mean Diff	**95% CI**	**Mean Diff**	**95% CI**	**Mean Diff**	**95% CI**
All Subscribers	-59.05 km^2	-60.52, -57.57	-58.26 km^2	-59.84, -56.67	-5.56 km^2	-7.35, -3.77
Mobile in at least 1 period	-299.0 km^2	-306.4, -291.7	-290.2 km^2	-298.0, -282.3	-21.3 km^2	-28.3, -14.3
Mobile in both periods	-208.0 km^2	-227.4, -188.7	-182.4 km^2	-201.2, -163.6	-25.4 km^2	-39.0, -7.68*

* $P = 0.0035$. For all other test, $P < 0.0001$.

"Intervention Period" is March 27-29; "Control (Pre-)" is March 20-22; "Control (Post-) is April 3-5.

Table S3. Results of a mixed effects ARIMA(1,0,2) model estimating the log-transformed trip count between chiefdom pairs, excluding Freetown.

	Parameter		Model Coefficient	
	Name	**Definition**	**Value**	**P-value**
Main Effects	National Lockdown	$= \begin{cases} 1, day \in (March\ 27, 28, 29) \\ 0, otherwise \end{cases}$	-0.318	<0.0001
	Cumulative Ebola Incidence	$= \frac{\text{Total Ebola incidence up to day } t \text{ in both chiefdoms}}{\text{Total chiefdom population}/1000}$	-0.001	0.0090
	Distance (15-30km)	$= \begin{cases} 1, & inter-chiefdom\ distance\ is\ 15\ to\ 30\ km \\ 0, & otherwise \end{cases}$	-0.186	0.0535
	Distance (>30km)	$= \begin{cases} 1, & inter-chiefdom\ distance\ is\ greater\ than\ 30\ k \\ 0, & otherwise \end{cases}$	-0.307	0.0032
	Operation Northern Push (destination chiefdom)	$= \begin{cases} 1, & chiefdom\ is\ in\ Kambia\ or\ Port\ Loko \\ & and\ day \geq June\ 16 \\ 0, & otherwise \end{cases}$	-0.061	0.0024
	Operation Northern Push (origin chiefdom)		-0.053	0.0093

Interaction	Lockdown*Incidence	---	-0.005	<0.0001
	Lockdown*Distance (15-30km)	---	-0.191	<0.0001
	Lockdown*Distance (>30km)	---	-0.967	<0.0001

Values are shown before exponentiation.
AIC=33397.21.

Table S4. Results of a mixed effects ARIMA(1,0,2) model estimating the log-transformed trip count between chiefdom pairs, allowing for location to be carried forward up to 2 days (left columns) or up to 3 days (right columns).

	Parameter	***t*-2 to *t***		***t*-3 to *t***	
	Name	**Value**	**P-value**	**Value**	**P-value**
Main Effects	National Lockdown	-0.285	<0.0001	-0.272	<0.0001
	Cumulative Ebola Incidence	-0.001	0.0036	-0.001	0.0019
	Distance (15-30km)	-0.288	0.0078	-0.324	0.0024
	Distance (>30km)	-0.442	<0.0001	-0.450	<0.0001
	Operation Northern Push (destination chiefdom)	-0.050	0.0042	-0.047	0.0054
	Operation Northern Push (origin chiefdom)	-0.039	0.0272	-0.024	0.1668
Interaction	Lockdown*Incidence	-0.005	<0.0001	-0.004	<0.0001
	Lockdown*Distance (15-30km)	-0.169	<0.0001	-0.144	<0.0001
	Lockdown*Distance (>30km)	-0.881	<0.0001	-0.788	<0.0001

Values are shown before exponentiation.
AIC = 38304.31 and 37442.37, respectively.

Table S5. Results of a mixed effects ARIMA(1,0,1) model estimating the log-transformed trip count between chiefdom pairs.

	Parameter Name	**Value**	**P-value**
Main Effects	National Lockdown	-0.314	<0.0001
	Cumulative Ebola Incidence	-0.001	0.0061
	Distance (15-30km)	-0.292	0.0085
	Distance (>30km)	-0.307	0.0057
	Operation Northern Push (destination chiefdom)	-0.066	0.0002
	Operation Northern Push (origin chiefdom)	-0.049	0.0075

Interaction	Lockdown*Incidence	-0.005	<0.0001
	Lockdown*Distance (15-30km)	-0.218	<0.0001
	Lockdown*Distance (>30km)	-1.015	<0.0001

Values are shown before exponentiation.
AIC = 39400.55.

Table S6. Unmatched results from crossover analysis.

	Users						Distance			
	# Calls	# Users	# Station-ary	Fraction Station-ary	Odds Ratio	P-value	Mean Inter-tower Distance	Ratio	Convex Hull Area	Ratio
Control (Pre-)	6,882,636	532,267	439,959	0.827	0.349	<0.0001	12.4 km	3.47	61.9 km^2	11.7
Intervention	5,343,388	480,469	447,796	0.932	ref	ref	3.57 km	ref	5.3 km^2	ref
Control (Post-)	7,221,813	544,568	454,543	0.835	0.370	<0.0001	11.6 km	3.25	55.4 km^2	10.45

"Intervention Period" is March 27-29; "Control (Pre-)" is March 20-22; "Control (Post-) is April 3-5.

Table S7. Sensitivity of crossover analysis to changes in the minimum travel distance.

	Fraction Stationary				OR
Minimum travel distance	**Control (Pre-)**	**Intervention**	**Control (Post-)**	**Control (Avg)**	***Control (Avg) versus Intervention***
0 km	0.368	0.527	0.381	0.375	0.539
3 km	0.652	0.840	0.670	0.661	0.371
10 km	0.827	0.932	0.835	0.831	0.359

Table S8. Sensitivity of crossover analysis to down-sampling of control periods.

		Users					Distance			
	Down-sample Fraction	# Active Subscribers Remaining	# Station-ary	Fraction Station-ary	Odds Ratio	p-value	Mean Inter-tower Distance	Ratio	Convex Hull Area	Ratio
Control (Pre-) ***Down-sampled***	22.4%	495,707	405,634	0.818	0.328	<0.0001	13.2 km	3.40	66.4 km^2	12.5
Intervention	N/A	480,469	447,796	0.932	ref	ref	3.57 km	ref	5.3 km^2	ref
Control (Post-) ***Down-sampled***	26.0%	422,827	501,878	0.826	0.348	<0.0001	12.4 km	3.47	60.0 km^2	11.3

Table S9. Sensitivity of crossover analysis results to changes in the minimum number of calling events required for eligibility.

	Fraction Stationary				Odds Ratio
Minimum # Calls	**Control (Pre-)**	**Intervention**	**Control (Post-)**	**Control (Avg)**	***Intervention is Reference***
≥2	0.827	0.932	0.835	0.831	0.359

≥5	0.782	0.916	0.795	0.788	0.341
≥10	0.737	0.903	0.756	0.747	0.317