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Original article

The impact of declaring the state of emergency on human mobility during COVID-19 pandemic in Japan

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ABSTRACT

Background/objectives: Japan has responded to the spread of COVID-19 through declaration of a state of emergency to regulate human mobility. Although the declaration was enforced by the government for prefectures, there is limited evidence as to whether the public complied with requests for voluntary stay at home. In this study, we evaluated the impact of declaring a state of emergency on human mobility during the COVID-19 pandemic in Japan.
Methods: We utilized daily human mobility data for 47 prefectures in Japan. Data were collected via mobile phone from February 1, 2020 to April 30, 2021. Difference-in-difference analysis was utilized to estimate the effects of the declaration of a state of emergency on prefectures in the Tokyo Metropolitan Area (Tokyo, Kanagawa, Saitama, and Chiba) in comparison to other prefectures where the state of emergency was first lifted (Osaka, Hyogo, Fukuoka, and Aichi).
Results: Human mobility was suppressed during the second state of emergency, from January 8 to March 21, 2021. However, the impact was weaker for the second state of emergency compared to the first.
Conclusion: In Japan, government requests for stay at home, such as the declaration of a state of emergency, were temporarily able to control human mobility. However, the second state of emergency was not as effective as the first. If additional need to regulate human mobility arises, self-restraint with stronger enforcement should be considered.

1. Introduction

The coronavirus infection (COVID-19) is caused by SARS-CoV-2, which was first identified in December 2019.[1] Most coronavirus infections cause only mild respiratory symptoms, but COVID-19 can progress to acute respiratory distress syndrome, which can be fatal.[2] Since the World Health Organization declared COVID-19 a global pandemic, deaths have continued to increase worldwide.[3] Initially, there was no standard for treatment, the infectivity of SARS-CoV-2 and the route of transmission were unclear, and nonpharmaceutical interventions (NPIs) were an important means of deterring the spread of the disease.[4] Most countries implemented NPIs, including human mobility restrictions, such as lockdowns. Recent reports have revealed that these NPIs are effective in deterring the spread of the virus.[5–7] In addition, the effectiveness of early infection control via lockdown has also been demonstrated.[4,8–10]

In Japan, a variety of NPIs have been implemented. In particular, the slogan, "closed spaces with poor ventilation," "crowded places with many people nearby," and "close-contact settings such as close-range" was branded as the slogan to avoid the "Three Cs!" In addition, the government recommended that the public incorporate basic infection prevention measures into its lifestyle.[11] On the other hand, restrictions on human mobility were not "enforced" by law in alignment with the lockdowns in other countries. Rather, Japanese lockdowns were

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"requested" by the government through declaration of a "state of emergency" in which the government encouraged people to voluntarily stay at home. Previous studies have analyzed the effect of the declaration of states of emergency on human mobility.[12–16] In particular, researchers have analyzed the effects of these declarations in the context of different settings and circumstances, including densely populated areas, nighttime dwellings, and commuting hours. However, to our knowledge, no study has evaluated the effect of states of emergency in Japan on human mobility utilizing a quasi-experimental method.

In Japan, it is unclear whether the reduction observed in human mobility during the states of emergency was the result of policy effects or public crisis awareness and voluntary action. When the first state of emergency was declared in April 2020, the disease picture of COVID-19 was unclear, and therapeutic agents were not yet approved.[17] However, by the time the second state of emergency was declared in January 2021, the disease picture of COVID-19 had become clearer, therapeutic agents had been approved, and the standard of care had also improved.[18] In addition, economic policies such as the "Go To Campaign" were implemented in September 2020 to increase human mobility by the end of the year.

This study examines effectiveness of state of emergency declarations by way of difference-in-difference analysis (DID) in order to understand the effect of the state of emergency on human mobility, an objective of the declaration. Since this is the first time in history that the government has enforced the declaration of a state of emergency,[19] it is important to clarify the trends of human mobility in Japan during this time period to inform the development future infection control measures.

2. Methods

In this study, we conducted a DID analysis of the impact on human mobility before and after the declaration of a state of emergency in prefectures in Japan utilizing LocationMind xPop by LocationMind, Inc. DID is a statistical method for quasi-experimental studies that utilizes observational data in order to estimate causal relationships.[20,21] Recent research has utilized DID to show that nonpharmaceutical interventions can reduce interactions, infections, and deaths.[22–24]

First, human mobility data were gathered for each prefecture to analyze trends during the COVID-19 pandemic. Next, we used DID to estimate the effects of NPIs among prefectures in the Tokyo Metropolitan Area (Tokyo, Kanagawa, Saitama, and Chiba) during the state of emergency in comparison to other prefectures where the state of emergency was first lifted (Osaka, Hyogo, Fukuoka, and Aichi). The two groups were similar in terms of population, population density, and geographic characteristics. DID was utilized to examine the intervention effects of the state of emergency declarations across the two groups.

Mobility data were collected from the prefectures from February 1, 2020 to April 30, 2021. Information was collected from individual location data gathered through mobile phone applications,[1] provided by NTT DOCOMO, INC, with the consent of the users. The data were processed collectively and statistically in order to conceal private information. The original location data were gathered utilizing Global Positioning System (latitude, longitude) information that was sent at a frequency of every 5 min at the shortest interval and did not include identifying information that specified individuals.

The mobility data used for the study included the daily interprefectural origin-destination mobility flow volume. Human mobility was logarithmically transformed. The value was calibrated using the national census to represent the total population of Japan. We estimated the following DID regression using prefecture level human mobility data: Let t be the date, x be the period where $x = 0$ represents the pretreatment period and $x = 1$ represents the posttreatment period. $Y(t,x)$ is indicative of the human mobility at date t and during the x period. Let $D(t,x)$ be the indicator of the state of emergency at date t and the period x, where $D(t,x) = 0$ indicates that the state of emergency was not declared and $D(t,x) = 1$ indicates that the state of emergency was declared. Then, the causal effect of the state of emergency α can be established following the DID forms:

$$\alpha = E[Y(t,1) - Y(t,0)|D(t,1) = 1] - E[Y(t,1) - Y(t,0)|D(t,1) = 0]$$

and be estimable by least squared regression, where $E[A|B]$ is the conditional expectation of A given B. We compared the human mobility of similar prefectures, such as that of the Osaka prefecture for $[Y(t,1) - Y(t,0)|D(t, 1) = 0]$and of the Kanagawa prefecture for $E[Y(t,1) - Y(t,0)|D(t,1) = 1]$ because these locations could have had reasonably had similar human mobility statistics if the state of emergency had not been declared. The sample size for the study included 84 days, covering 21 days before and after the declaration of the state of emergency in each prefecture.

The measurement targets were prefectures that had independent periods of emergency declarations and prefectures whose populations and human mobility statistics were similar. The period of emergency declaration and the target prefectures are shown in Fig. 1.

Next, DID analysis was conducted in the areas where the state of emergency was first lifted (Gifu, Aichi, Kyoto, Osaka, Hyogo, and Fukuoka) and where it was continued (Tokyo, Kanagawa, Chiba, and Saitama) during the second declaration of state of emergency. These data points were classified as a "stay" if the person had stayed for more than 1 h without exceeding the threshold (1 km). Therefore, there is a possibility of missing data in the case of movement outside the prefecture. Since we were only examining the effects of the declaration of the state of emergency from the perspective of human mobility, we believe that excluding movements outside of the prefecture would impact our results. Moreover, Tokyo was not included in this study because it has a particularly large population and population density, and there were no appropriate prefectures to use as comparison data. In addition, 2 × 2 table described the outcome (Average Treatment Effect) by time and treatment was shown in the supplement tables. All analyses were conducted using R version 4.1.1.

3. Results

Results revealed that the emergency declaration was effective in reducing human mobility with a significant difference between the prefectures where the state of emergency was continued versus the prefectures where the state of emergency ended.

The main intervention effect evaluated in this study was the reduction of human flow due to the second declaration of emergency. The second emergency declaration was issued from January 8 to March 21 for the four Tokyo Metropolitan Area prefectures (Tokyo, Kanagawa, Saitama, and Chiba) and from January 13 to February 28 for the other

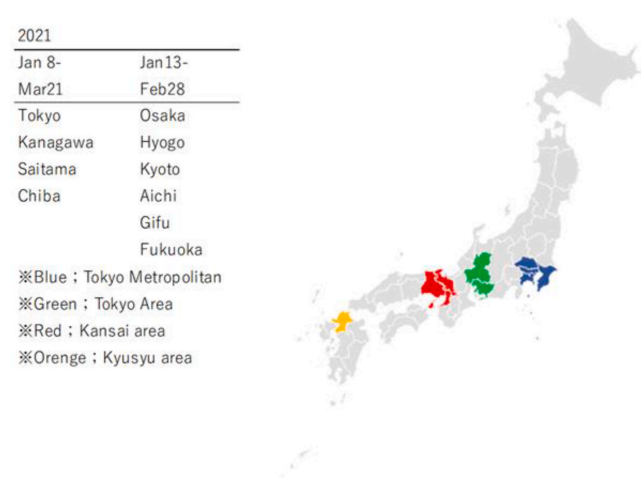

Fig. 1. Prefectures of the 2nd state of emergency in Japan.

six prefectures (Osaka, Hyogo, Kyoto, Aichi, Gifu, and Fukuoka) (Fig. 1). If the second declaration of state of emergency had retained its intervention effect, human mobility in the six prefectures where the state of emergency was first lifted would increase more in comparison to the Tokyo Metropolitan Area. However, DID revealed that in Osaka, Hyogo, Aichi, and Fukuoka, which are prefectures with similar population size and density as the Tokyo Metropolitan Area (Table 1),[1] human mobility was suppressed during the state of emergency. All results are shown in Table 2.

The following is a list of the prefectures that were compared in this study:

(1) Kanagawa compared with Osaka, Aichi, Fukuoka, and Hyogo

After the state of emergency was lifted, human mobility in Osaka, Aichi, Fukuoka, and Hyogo increased, and the DIDs estimates were statistically significant at 21 days in Osaka (estimate = 97.7%; CI = 96.5%–98.9%), in Aichi (estimate = 97.2%, I = 95.8%–98.6%), in Hyogo (estimate 96.3%; CI, 95.0%–97.5%), and in Fukuoka (estimate = 96.4%; CI = 95.1%–97.7%).

(2) Chiba compared with Osaka, Aichi, Fukuoka, and Hyogo

After the state of emergency was lifted, human mobility in Osaka, Aichi, Fukuoka, and Hyogo increased, and the difference-in-differences estimates were statistically significant at 21 days in Osaka (estimate = 97.3%; CI = 96.2%–98.4%), in Aichi (estimate = 96.7%; CI = 95.4%–98.0%), in Hyogo (estimate = 95.8%; CI = 94.7%–96.9%), and in Fukuoka (estimate = 95.9%; CI = 94.7%–97.2%).

(3) Saitama compared with Osaka, Aichi, Fukuoka, and Hyogo

After the state of emergency was lifted, human mobility in Osaka, Aichi, Fukuoka, and Hyogo increased, and the difference-in-differences estimates were statistically significant at 21 days in Osaka (estimate = 98.1%; CI = 97.0%–99.1%), in Aichi (estimate = 97.5%; CI = 96.3%–98.8%), in Hyogo (estimate = 96.6%, CI = 95.5%–97.7%), and in Fukuoka (estimate = 96.7%, CI = 95.6%–97.9%).

Since the state of emergency in Osaka, Aichi, Fukuoka, and Hyogo was lifted on February 28, and the state of emergency in the Tokyo Metropolitan Area lasted until March 21, we conducted a DID for 21 days before and after March 1.

Table 2
Results of difference-in-difference analysis for the second state of emergency.

Prefecture	Estimate	95% CI			p value
Kanagawa - Osaka	97.7%	96.5%	to	98.9%	<0.01
Kanagawa - Aichi	97.2%	95.8%	to	98.6%	<0.01
Kanagawa - Hyogo	96.3%	95.0%	to	97.5%	<0.01
Kanagawa - Fukuoka	96.4%	95.1%	to	97.7%	<0.01
Chiba - Osaka	97.3%	96.2%	to	98.4%	<0.01
Chiba - Aichi	96.7%	95.4%	to	98.0%	<0.01
Chiba - Hyogo	95.8%	94.7%	to	96.9%	<0.01
Chiba - Fukuoka	95.9%	94.7%	to	97.2%	<0.01
Saitama - Osaka	98.1%	97.0%	to	99.1%	<0.01
Saitama - Aichi	97.5%	96.3%	to	98.8%	<0.01
Saitama - Hyogo	96.6%	95.5%	to	97.7%	<0.01
Saitama - Fukuoka	96.7%	95.6%	to	97.9%	<0.01

The trend of human mobility in Japan during the assessable period is shown in Fig. 2. Human mobility tends to decrease during vacation periods (such as the Obon holiday, the new year, and Golden Week). Although the first declaration of state of emergency coincided with the Golden Week holidays, a time when human mobility already tends to decrease, the effect of reducing human mobility during the period was clear (Fig. 1). On the other hand, human mobility increased during the period of the second state of emergency. This might be the reason that the first declaration of state of emergency came into effect during the Golden Week holidays and was issued nationwide, while the second was limited to prefectures with a large number of infected people.

4. Discussion

This quasi-experimental study analyzed the changes in epidemic dynamics before and after a state of emergency was declared between January and March 2021. We conducted DID to examine the effect of the state of emergency on human mobility in the Tokyo, Kanagawa, Chiba, and Saitama prefectures, which are the most densely populated metropolitan areas in Japan, and the human mobility of the Osaka, Hyogo, Aichi, and Fukuoka prefectures, which are areas where the state of emergency was lifted earlier. Results showed that the state of emergency was effective in reducing human mobility, with a significant difference found in the Tokyo Metropolitan Area, where the state of emergency was continued. In this study, we only examined the intervention effect of the state of emergency requested by the government and did not consider the effect of infection control measures taken by the prefectures

Table 1
Tokyo has ahigh population and population density and there are no comparable prefectures in the volume of huma mobility.

Prefecture	Area	Total population	Size	Average age	Population composition ratio [by age]		Population density (person/km^2)	Human mobility ratio before and after the 1st state of emergency (%)
					<15 years old (%)	>65 years old (%)		
Tokyo	Tokyo metropolitan	14,047,594	–	45.3	11.2	22.7	6402.6	80.7
Kanagawa	Tokyo metropolitan	9,237,337	A	46.5	11.8	25.6	3823.2	88.0
Osaka	Kansai	8,837,685	A	47.1	11.7	27.6	4638.4	86.9
Aichi	Tokai	7,542,415	B,C	45.6	13.0	25.3	1458.0	84.8
Saitama	Tokyo metropolitan	7,344,765	B	46.8	11.9	27.0	1934.0	91.0
Chiba	Tokyo metropolitan	6,284,480	C	47.1	11.7	27.6	1218.5	89.9
Hyogo	Kansai	5,465,002	C,B	48.0	12.2	29.3	650.6	88.3
Hokkaido	Hokkaido	5,224,614	–	49.8	10.7	32.1	67	86.6
Fukuoka	Kyushu	5,135,214	C,B	46.7	13.0	27.9	1029.8	87.0
Shizuoka	Tokai	3,633,202		48.4	12.1	30.1	467.2	88.5

A = Kanagawa and Oska; B = Saitama and Aichi, Hyogo, Fukuoka; C = Chiba and Aichi, Hyogo, Fukuoka.
※ A DID analysis used Kanagawa, Saitama, Chiba and other prefectures with similar population and population density as controls.
※ The first-round state of emergency began on April 7 in Tokyo, Kanagawa, Saitama, Chiba, Osaka, Hyogo and Fukuoka, and on April 16th in other prefectures.
※ Hokkaido has a low population density as a prefecture, with about 40% of the population concentrated in Sapporo city.

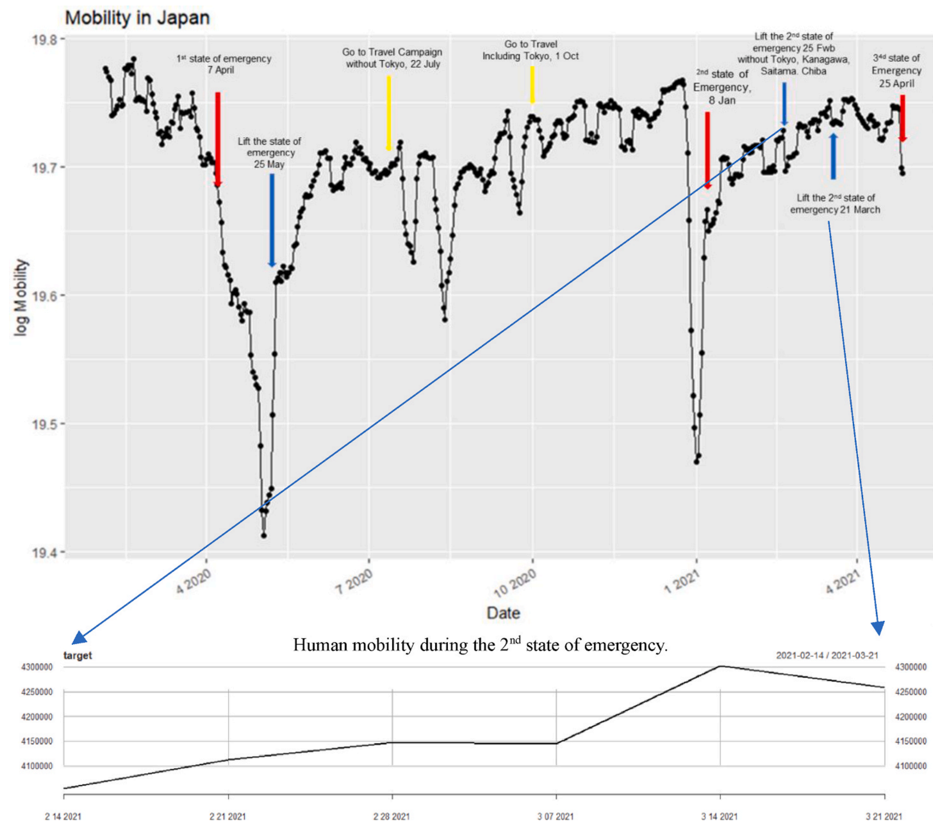

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Fig. 2. National human mobility and timing of major policy interventions in Japan.

independently. As for the impact of the lag, an increasing trend in human mobility was observed even before the state of emergency declaration was lifted. Therefore, we considered the intervention effect of the state of emergency to be clear, even though the results may have been weakened. However, although the effect of the second state of emergency declaration was statistically significant, the suppression of human mobility was slight, suggesting that the effect was already small during the second declaration.

Although human mobility control has been shown to be associated with lower infection rates as an effective NPI,[5–7] there have also been reports of economic impacts and other health hazards, such as increased suicide rates.[25] The policies of countries around the world in response to the COVID-19 pandemic differed,[1,22] with respect to NPIs also varying.[4,26,27] For example, the United Kingdom and the United States implemented lockdowns to protect their populations from rapid increase in number of infections and deaths, while some countries, such as Sweden, resorted to voluntary social distancing, fearing that mandatory regulations would reduce health risks but not economic risks. Some countries resorted to voluntary social distancing out of concern that the cost would be too high.[28] Others, such as Germany, opted for a time-bound approach because human mobility restrictions were criticized as being unreasonably harsh, economically, given the lethality of COVID-19. While some countries adopted a lockdown policy to significantly limit human mobility, Japan requested voluntarily stay home via state of emergency declaration because the government could not legally enforce a lockdown. The United States and various European countries were "required" to stay at home (with some exceptions), while the people of Japan were given the "recommendation" to stay home, which was similar to the voluntary measures taken in Sweden.[29] Sweden had 796,266 infected cases and 9113 deaths as of March 31, 2021, while Japan had 472,112 infected cases and 13,602 deaths,[3] which is clearly low in terms of the population ratio. Although there are no perfect statistics for comparison, Japan's COVID-19 measures appear to have been relatively successful.

Although there are reports on the effect of declaring a state of emergency on reducing human mobility,[12–16] it is unclear whether these effects are due to voluntary curtailment of human mobility because of the health risk of COVID-19 or because it was requested through the state of emergency. At the time of the first state of emergency, around April 2020, the clinical course, transmission patterns, and severity factors of COVID-19 were unclear, and therapeutic agents had not yet been approved.[17] The high fatality rate among the elderly was apparent, and, in Japan, where the population is the oldest in the world, the health risk of COVID-19 might have been a reason for people to voluntarily isolate. However, by January 2021, when the second state of emergency was declared, the clinical and transmission patterns of COVID-19 had been elucidated, therapeutic agents had been approved, and the standard of care had improved.[18]

In addition, economic policies, such as the Go To Travel campaign, were implemented, and COVID-19 was no longer considered as an unknown disease. Under these circumstances, the fact that the second declaration of state of emergency impacted human mobility is an interesting result. On the other hand, although the effect of the second emergency declaration was statistically significant, the suppression of human mobility was slight, suggesting that the effect of the declaration was limited during the second round. Japan has now had up to the sixth wave of the COVID-19 pandemic, and up to the fifth wave, even the slight effect of suppressing human flow through measures such as declaring a state of emergency, combined with other NPIs, has succeeded in preventing the spread of infection. However, after the 6th wave, i.e., when the strain has repeatedly mutated to become an omicron strain and its infectivity has increased, it may become difficult to prevent the spread of the disease through voluntary restraints based on requests that are not legally binding. Although the omicron strain has a strong transmission ability and a weak virulence compared to conventional strains and previous mutant strains, it might be the time to consider the use of legal measures that would allow stronger regulation of human mobility in case a new virus with stronger transmission ability and even higher lethality emerges in the future.

A limitation of this study is that the collection of mobile data cannot fully measure human mobility. Therefore, it is difficult to make definitive epidemiological conclusions through this study. In addition, this study compared human mobility during the declaration of the state of emergency from January 8 to March 21 after the declaration was lifted, instead of comparing it with the end of the year and the beginning of the year, when human mobility decreases due to obtain a regression. Additionally, a third state of emergency was enacted in Tokyo on April 25, 2021, and there was a clear increase in human mobility compared to the same period in 2020 (Fig. 2). Although this is an interesting trend, the period of data analyzed was specifically from February 1, 2020 to April 30, 2021, so it was not possible to study the trends of human mobility in detail after the third of the state of emergency. In Japan, the declaration of a state of emergency can be effective, but its effectiveness may be weakened with increase in the duration and the number of times it is enforced. Per results of this study, there is a difference between the rate of decrease in human mobility at the time of the first declaration (April–May 2020) and the rate of decrease at the time of the second declaration (January–March 2021), suggesting a decline in the effect of the policy over time. Further research on the effects of declaration of a state of emergency after the third declaration is indicated, and continuous evaluation will be necessary for future infectious disease control measures.

In Japan, government requests to stay at home, such as the declaration of a state of emergency, were effective for decreasing human mobility. However, the second declaration of state of emergency was not as effective as the first, and in order to better regulate the overall mobility of people, consideration self-restraint with stronger enforcement may be indicated.

Author contributions

Nakamoto, Kawakami, Nojiri and Kuroki have full access to all of the data in this study and takes responsibility for the integrity of the data and accuracy of the data analysis. Concept and design: All authors Acquisition, analysis, or interpretation of data: All authors Drafting of the manuscript: All authors Critical revision of the manuscript for important intellectual content: All authors Statistical analysis: Nakamoto, Kawakami.

Obtained funding

None.

Conflict of interest disclosures

Nakamoto is an employee of Gilead, Japan. Other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cegh.2022.101149.

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