Development Report:

Continuous Efforts Leads to a Value for Hypertensive Patients: Development of a Casual Smart Na/K Meter and Smart Na/K Application Linked by NFC to Android

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[Received March 18, 2020; accepted July 20, 2020]

This study develops a casual smart Na/K meter to measure the sodium and potassium in urine for hypertensive patients. To prevent hypertension from leading to cardiopathies, it is useful to reduce salt intake. The Omron Healthcare Co., Ltd. lunched the prototype, a casual Na/K meter to measure the salt intake from a diet. Nevertheless, it lacks the function to make the patients grasp the historical data. This study improves that meter by adding the NFC and developing the software application linked to Android smartphones and smart watches. Smartphones can store the data and display the historical data. Smart watches make up a part of their daily lives by alerts and messages. The concept of this study provides a continuous value for hypertensive patients. That value is similar to the learning value but it exists beyond the learning effect. For the learning value, after the subjects learn something and obtain the skills, ability, and knowledge, the value is fixed and completed. On the other hand, for the continuous value, the learning value is also included and the subjects receive the learning value; however, they need to continue that behavior until death. If they stop reducing salt intake, they return to hypertension. If they get satisfied with obtaining the learning value and stop their actions, they never receive the continuous value that exists beyond the learning value. The continuous value is brewed in the transtheoretical model of health behavior change. Throughout these stages, to encourage their behavioral change and obtain the continuous value, this study employs Fogg's theory applied to developing the communication devices. The application stocks the historical data and displays it on the smartphones. The smart watches classify alerts into five colored displays from green (good) to red (bad). It can be helpful for the patients to make the reduction of salt intake as their dietary habit. In the future, the application needs to be improved for making patients adapt with their diets and motivations.

Keywords: continuous value, smart meter, Android, NFC, health behavior change

1. Introduction

Increasing the intake of sodium increases the blood pressure, which cause the hypertension. Hypertension is defined as the systolic and diastolic blood pressures higher than 140/90 mmHg. Hypertension causes cardiopathies, nephropathies, and stroke.

In Japan, an overdose of salt is one of the main factors leading to high blood pressure; nevertheless, many Japanese meals such as miso soup and pickles have a lot of salt. The average salt intake for a Japanese per day is about 10.6 g [1], whereas 6 g is recommended by Japanese Society of Hypertension [2] and less than 5 g by the World Health Organization (WHO) [3]. It is said that about half of the Japanese are genetically sensitive to salt, and there are many hypertensive patients due to excess salt consumption [4]. In addition, Japanese tend to practice less intake of vegetables and fruits (which contain potassium) that eliminate salt from the body and suppress blood pressure.

There are nearly 43 million patients with hypertension in Japan, and only 9 million receive medical care [2]. The annual medical costs in Japan amounts for 372.72 billion USD, while the cost for hypertension is around 17.57 billion USD [5].

Hypertension has been called the "silent killer" because hypertensive patients are often asymptomatic; therefore, the ignorance about hypertension and its relationship with salt intake similarly demotivates Japanese individuals from reducing their salt intake to prevent hypertension.

Managing salt and potassium intake is important for managing hypertension; however, the measurement of salt intake in the diet requires a 24-h urine storage test that accumulates all or some portion of the urine for a day and analyzes it in a medical institution. This procedure is too cumbersome for patients to follow the data.

In 2014, Omron Healthcare Co., Ltd. launched a simple measurement of urine Na/K (sodium and potassium) ratio (hereinafter, the casual Na/K meter). However, it was developed as the prototype device for medical researchers not for patients. Hence, there was the absence of the function to store the historical data and to make patients see it easily.

We aimed to improve the casual Na/K meter from urine to prevent hypertension by adding the NFC and developing applications for smartphones and smart watches. These improvements add the continuous value, defined as the value for keeping continuous motivation, to the patients.

In the next section we introduce the casual Na/K meter. Section 3 defines the continuous value. Section 4 introduces the theory behind the continuous. Sections 5 and 6 explain the application. Section 7 discusses and Section 8 concludes.

2. Casual Na/K Meter

Omron Healthcare Co., Ltd., developed a simple system for the measurement of the urine Na/K ratio for medical researchers. The modeling number is HEU-001F as shown in **Fig. 1**.

In the process of developing a convenient alternative to the 24-h urine storage test, the global epidemiological INTERSALT study showed the association between blood pressure and urine Na/K (sodium/potassium ratio) [6].

Finally, Omron Healthcare found that the numerical value measured by simply applying urine to the sensor once a day for about a week is almost equivalent to the conventional method of 24-h urine storage. This makes it possible to easily grasp the Na/K ratio in everyday life with high precision, and patients can easily check the daily salinity and potassium intake status of individuals who have been difficult to grasp [7].

The device is used according to the following steps.

1. Patients collect their urine into a cup.
2. Patients dip the Na/K meter sensor into the cup.
3. The meter displays the Na/K ratio instantaneously.
4. Researcher collects the meter.
5. Researcher puts the meter on the recording device to send the data in the meter to the server by Omron Healthcare.
6. Researcher accesses the server and obtains the data as a csv file.

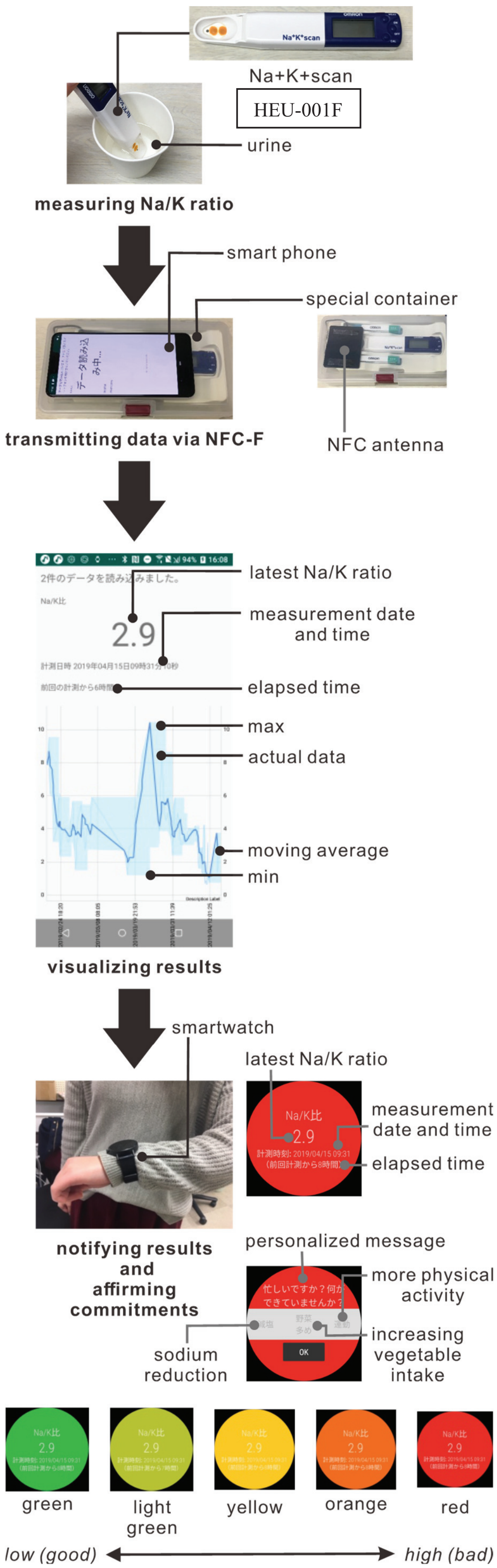

Fig. 1. A flow for measuring and recording the Na/K ratio.

Omron Healthcare assumed that this casual Na/K meter is used by medical researchers. They did not build in the mechanism by which the patients could obtain the historical data by themselves, which means that the patients need to take a memo to record the Na/K ratio to grasp the data in their diets. Unfortunately, the data server run by Omron Healthcare cannot be accessed by the patients. It is for the medical researchers. Therefore, it is too cumbersome for the patients to check and remember their Na/K ratio every day.

This study improves the casual Na/K meter by adding the NFC to store the historical data and develop the application to display that data on Android smartphones and smart watches. These types of wearable devices can be used as a tool for preventing and managing hypertension, by accurately capturing the change in the diet situation due to dietary guidance for patients with high blood pressure.

Previous studies show that the wearable devices improve patient's health [8–13]. The types of wearable devices vary with parts of body [14]. In addition, the wearable device directly affects the human body condition by influencing the body temperature [15].

3. Value Creation

The challenge for the prevention and treatment of hypertension is how to increase potassium intake from fruits and raw vegetables that reduce salt and counteract its harmful effects. The casual Na/K ratio meter connected with the smartphone application (hereafter smart Na/K meter) allows patients to easily know the Na/K ratio in their diets.

The historical data makes it easy to see the effect of reducing salt and increasing potassium intake, and it seems to be a great force to support continued diet. When used in conjunction with blood pressure measurement at home, patients can also know the effect of diet on blood pressure reduction, which should help to continue improving dietary habits. Especially, to prevent hypertension, the conditions for reducing salt intake are important because humans eat every day and the salt intake predisposes to hypertension.

There are three types of stakeholders surrounding the Na/K meter: the producer of Omron Healthcare, the medical researcher, and the patients. First, Omron Healthcare assumes that the medical researcher uses that meter. Nevertheless, this study assumes that this meter is adapted to the patients by improving usability with NFC and software applications working in smartphones and smartwatches.

This study defines that the value adding to the patients is the continuous value. In medical treatment, it is important to help patients to continue paying attention to disease prevention. The transtheoretical model of health behavior change (well known as stages of change model) suggests the following stages [16]. Here we introduce the explanation following Christine Bundy [17].

> "These stages include *pre-contemplation*, when the individual is not considering change; *contemplation*, when they are favorably disposed to change but have not made concrete plans or adopted any action; *planning*, when strategies have been selected but not yet used; and *action*, when attempts have been made to, for example, stop smoking, lose weight, or adhere to some other health advice; and finally the *maintenance* phase, when people make deliberate attempts to continue with the change program" (l.6-14, p. 97).

These stages can be applied into the hypertension treatment. It is generally criticized that patients tend to lose the motivation for reducing salt intake. There are some reasons. For instance, reducing salt in food makes it lose its taste, which decreases the patients' motivation. Additionally, in Japan, the medicine for reducing blood pressure, Angiotensin II Receptor Blocker (ARB), is cheap and very effective. The patients easily rely on it, which reduces their motivation for the reduction of salt intake [18].

Following the theoretical model, this study focuses on the contemplation stage. In that stage, patients start to try some action but have not yet adopted it. If they fail at any attempt, they easily give up and go on the next planning stage to make a new plan. To prevent such a motivation reduction, this study makes the patients grasp the historical data and notice the unhealthy habit by the alert given to the patients by the continuous value.

The sense of this value is similar to the learning value. But in this study, the meaning of continuous value has an essential difference. For learning value, the subjects learn something and obtain the skills, ability, and knowledge [19, 20]. At the end of learning, the value is completed. On the other hand, for the continuous value, the learning value is also included and the subjects receive the learning value but they need to continue that behavior until death. If they stop reducing salt intake, they return to hypertension. If they get satisfied with obtaining the learning value and stop their actions, they never receive the continuous value that exists beyond the learning value.

4. Persuasive Technology

The transtheoretical model of health behavior change is just a theory. To make a bridge between that theory and developing the Internet of Things (IoT) tool, this study employs Fogg's theory.

Fogg proposed the behavior model to explain that, when a person performs a target behavior, he/she must be sufficiently motivated, have the ability to perform the behavior, and be triggered to perform the behavior [21]. Information and communication technologies can affect his/her motivation and ability, as well as provide effective triggers in order to persuade him/her to change the behavior. Such a technology is named "persuasive technology" [22].

From the view of software development, Oinas-Kukkonen and Harjumaa reshaped the persuasive design principles that Fogg proposed in the following "primary task support" [23].

1. *Reduction* – A system that reduces complex behavior into simple tasks helps users perform the target behavior, and it may increase the benefit/cost ratio of a behavior.
2. *Tunneling* – Using the system to guide users through a process or experience provides opportunities to persuade along the way.
3. *Tailoring* – Information provided by the system will be more persuasive if it is tailored to the potential needs, interests, personality, usage context, or other factors relevant to a user group.
4. *Personalization* – A system that offers personalized content or services has a greater capability for persuasion.
5. *Self-monitoring* – A system that helps track one's own performance or status supports in achieving goals.
6. *Simulation* – Systems that provide simulation can persuade by enabling them to observe immediately the link between the cause and its effect.
7. *Rehearsal* – A system providing means with which to rehearse a behavior can enable people to change their attitudes or behavior in the real world.

They also classified "computer-human dialogue support" into praise, rewards, reminders, suggestion, similarity, liking, and social role. On the one hand, the primary task support assists the user in achieving the target behavior for which they are using the system. In contrast, the dialogue supports incorporate feedback to the user in the form of dialogue to engage in the target behavior. The design principles including these supports were applied to web-based interventions for promoting health and health-related behavior [24, 25] and mobile applications promoting physical activity [26].

5. Smart Na/K App

We have developed the "Smart Na/K App" running on Android OS. The app is designed to foster the awareness of eating behavior and physical activity to prevent hypertension based on the urinary Na/K ratio. We explored and made decisions on the app design issues (see the next section for some details). **Fig. 1** shows the flow of the measurement and recording of the Na/K ratio.

To measure the spot urinary Na/K ratio, a portable device "Na+K+scan" (HEU-001F; Omron Healthcare Co., Ltd.) was used. It has a length of 164 mm, a width of 29 mm, a height of 20 mm, and a weight of approximately 50 g. It can measure Na/K ratios ranging from 0.1 to 19.9 usually within 1 min. After the measurement, the user stores it in a special container in which the NFC antenna (EXA-30; Aisan Electric Co., Ltd.) is embedded. To start transmitting the data measured via the NFC-F, the user should open the app and put the smartphone on the container.

After receiving the data from the device, the data is stored in the database and the app displays the latest Na/K ratio, its measurement date and time, elapsed time since the last measurement, and the graph representing the time series data. In the graph, the simple moving average of 10 samples is shown by a bold blue line. The range between the minimum and maximum values within the 10 samples is visualized by a light blue background. The actual Na/K ratio for each measurement is also plotted by a thin blue line.

Finally, the notification is sent to the smart watch. The user can see the latest Na/K ratio, its measurement date and time, and the elapsed time since the last measurement with one of the following five background colors: green, light green, yellow, orange, and red. These colors are like the five points Likert scale and help users to interpret the Na/K ratio.

There is no generally acceptable target value for the Na/K ratio. The WHO guidelines recommend less than 1 [27], Yatabe et al. discussed that less than 2 might be reasonable [28], and Iwahori et al. expected that the target value in the Japanese population may be less than 3 [7]. Therefore, the app should keep encouraging users to minimize their Na/K ratio at any time. The background color is the tailored feedback for each user to support the self-monitoring of his/her dietary habit. The color is selected by the threshold based on their past measurements as shown in **Table 1** where x_i is the latest Na/K ratio. μ and σ are the average and the standard deviation, respectively, of all Na/K ratios measured in the past.

For example, the green/red background shows that the current value is relatively low (good) / high (bad) in comparison with the user's previous values. For each background color except for yellow, we preset the tailored messages to affirm the user's commitments to foster the awareness of eating behavior and physical activity (also shown in **Table 1**). To answer the message, the user should select "sodium reduction," "increasing vegetable intake," and/or "more physical activity." The user's selection is also stored in the database. For the red background, the app asks the user to regret his/her insufficient behavior. For the orange and light green backgrounds, the app makes the user aware of his/her good behavior. Even in the green background, the app shows the message to motivate further behavioral changes for minimizing the Na/K ratio. For the yellow background, the app does not show any message. That is to avoid a stereotyped routine to show and confirm messages and keep the user paying attention on them.

Additionally, the app sometimes sends the following notifications to the smartwatch at noon. If the background of the last measurement was red, "What will you be aware of this afternoon?" and selection of the commitments will

Table 1. Thresholds and personalized messages.

Background color	*Threshold*	*Message translated to English (original message in Japanese)*
Red	$1.64\sigma < x_i - \mu$	Are you busy? What are you not working on? （忙しいですか？何ができていませんか？）
Orange	$0.84\sigma < x_i - \mu \leq 1.64\sigma$	How are you? What are you striving for? （調子どうですか？何をがんばっていますか？）
Yellow	$-0.84\sigma < x_i - \mu \leq 0.84\sigma$	*No message*
Light Green	$-1.64\sigma < x_i - \mu \leq -0.84\sigma$	Good work! What have you been aware of? （調子良いですね。何に気を付けていますか？）
Green	$x_i - \mu \leq -1.64\sigma$	Excellent! What will you try next? （絶好調ですね。これから何をがんばりますか？）

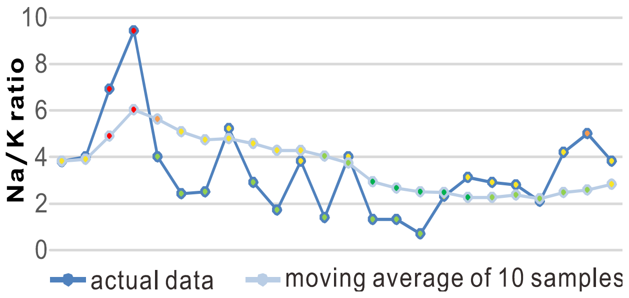

Fig. 2. Na/K ratio and background color.

be displayed. If the background was orange, there will be a 50% chance of displaying the same message. If 48 h or 72 h have elapsed since the last measurement, preset messages for each background color to recommend the measurement of the new urinary Na/K ratio will be displayed. In this case, the user should select the preferred time for the next measurement from "now," "later," or "never." If "later" is selected, the user will be asked to specify the time for the measurement. These notifications are aimed at keeping up the user's interest in measuring the urinary Na/K ratio and improving the eating behavior and physical activity.

6. Preliminary Data Collection for Designing the App

To make decisions on design issues of the app, one of the authors measured the urinary Na/K ratio twice a day, at wake up time and bedtime, from February 8, 2019 to May 17, 2019. **Fig. 2** shows a part of the data measured. The color of each point shows the background color of smartwatch notifications decided by the thresholds in **Table 1**.

The smartwatch notification is crucial for the app to persuade the user to change his/her behavior. We considered using the actual data of the Na/K ratio or the moving average of 10 samples as a trigger of the notifications. That is because the Na/K ratio sometimes exhibits swift fluctuations and the moving average would reduce the effect. As shown in **Fig. 2**, the actual data have several spikes with different background colors. The moving average does not have such fluctuations and the background color changes gradually.

It was a conscious choice to use the actual data as the trigger because the app should notify the user when these spikes were observed. For example, one of the spikes was observed just after eating ramen noodle. Such a quick feedback in the smartwatch seems useful for the user to understand what went right or wrong. However, it seems useful for the user to understand the trends of the Na/K ratio. We also decided to display the line graph of the moving average on the smartphone screen.

7. Discussions

This study adds NFC to the casual smart Na/K meter and develops software application for Android connected to smartphones and smart watches. The point of this development is making the patients remember and learn the intake of salt. The process of learning is affected by the continuity of the measurement of the Na/K ratio. It is well known that the Na/K ratio varies during the daytime. In this study, the most important indicator for the patients is the movement, that is, moving average. They can learn their own efforts by those movements. This learning effect is the continuous value that we earlier defined. Unfortunately, there is uncertainty of the value that each participant perceives in these movements. It is well known that a good feedback encourages the motivation, and vice versa. Therefore, there is a chance to customize the parameter of alert for the smart watches for each person. Someone who applied good efforts needs to set strict parameters than this study but those who applied poor efforts need to set lenient parameters.

Kanji Ueda proposed the value creation model in the aspect of information uncertainty between the provider and receiver and the environmental uncertainty surrounding those stakeholders. The model is classified into three classes; I) providing value, II) adaptive value, and III) co-creative value. In the health care services, Class I is often applied because the service is provided by the medical institution one-sidedly. However, even in Class I, the value for the attributes or function for service or product varies with the subject types and the information they received [29].

In this study, we assume that the patients would like to recover the blood pressure. It is difficult to measure the amounts of sodium intake but it is easy to measure the Na/K ratio. The Na/K ratio is a useful measurement for knowing the amounts of sodium intake as the signal because they are related. Considering this, we made an alert on the past Na/K ratio.

But there is still a chance to customize the alert based on the patients' behavior. In this meaning, the development of the application of the smart casual Na/K meter is applied by the Class II model. The provider gives a permission for the patients to customize the parameter to fit their dietary behavior. To achieve such an adaptation, the communication between the provider and receiver is highly needed in the future.

Additionally, this system can be more expanded to include measurements for other factors including Mg. Generally, a table of salt contains 99% of sodium. On the other hand, there are different kinds of salt sold in the market. They are called Algae Salt, defined as salt made by the mixture of sea salt with seaweed. Seaweed includes enough minerals such as potassium and magnesium. Potassium is useful to cancel out sodium intake so that the Na/K ratio is important for the alert of hypertension. Magnesium also has health benefits. Thus, measuring magnesium is also a useful alert for encouraging good health to prevent hypertension.

There are two other limitations. First, the lack of in-depth and longitudinal studies on the system. In this study, we have focused on increasing the patients' value of the casual Na/K meter. However, to evaluate and improve the effectiveness of the system, we need to conduct nontraditional usability tests, for example "technology probe" [30]. That is because we should install a technology into a real-world setting and then observe and analyze how the system is used, who the actual users are, and what types of persuasive technology could be successfully used in these settings by these users.

The second limitation concerns the iOS application. Android is more open than iOS. This study aims to first develop the prototype of application for Android and then obtain the data. Throughout this process, the application and the parameter setting of alerts from smart watches will be modified. The NFC system in iOS is protected by Apple so that the cost of connecting the NFC in the smart Na/K system to iOS will be increased.

The next issue is to overcome these limitations. Obtaining the data from the broadly hypertensive patients helps develop a more robust algorithm for making alerts. This system is also useful for the young generations to prevent hypertension.

Additionally, in the aspect of value creation, it is important to develop the system including feedback for patients' reflections on their lifestyle and health motivation. In this regard, the system can be expanded to the Class III model for co-creation among patients, doctors, and system developers. Hypertension is very famous health problem that has not yet been solved in the medical field. They have been ringing the alarm bell "Less salt, More move." It does not lead to a radical solution for preventing hypertension. The Class III type of co-creation will shed a new light for preventing hypertension.

The cost of medical treatment of hypertension becomes ten-fold in the generation with more than 45 years old. To reduce its cost, the smart application is useful to make reductions of salt intake as a habit for the younger generations.

To adapt for the life style and mass customization, the log system will be improved and applied into appropriate service strategies [31, 32]. Ultimately, a perfect customized smart application would change from the Class I service to the Class II service [33]. It will be very different from the present health service one-sidedly provided by the medical institutions. It should be included in the dynamics for patients' optimization of their health conditions.

The achievement and success of this system lead to the reduction of the social medical cost of hypertension and its associated diseases.

8. Conclusions

This study developed the smart Na/K meter and smart Na/K application linked by NFC to Android. The historical data in the diets are displayed in the smartphones. The data is calculated by the specific algorithm following Fogg's theory to send alerts to patients until it becomes their habitat. These functions are helpful to make the patients continue their motivation to reduce salt intake. In this regard, this new device provides the continuous value for the patients.

Acknowledgements

This study is supported by the strategic foundation provided by the Shimane University. For introducing NFC into the casual Na/K meter, Omron Healthcare Co., Ltd. opened the information of technology and helped the construction of the systems.

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