VERIFICATION OF PROPOSED DRIVER ALCOHOL DETECTION METHODOLOGY OF ELECTRODERMAL ACTIVITY USING ELECTROENCEPHALOGRAMS AND PATCH TESTS

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ABSTRACT

This paper describes the verification of alcohol detection methodology that measures changes in electrodermal activity (EDA) using electroencephalograms and conductive patch tests. We tested the methodology using a direct current potential method. First, it was revealed that the direct current potential method could detect alcohol in 70% of human subjects by analyzing absolute values of data waves or through a post-processing method. Second, mice that do not sweat were tested to observe the changes in EDA values before and after they were injected with alcohol because EDA might be affected by sweat in humans. Third, to clarify the local mechanism of EDA, fluctuations in ion concentration distribution were analyzed using artificial cells. The results indicate that EDA changed significantly before and after drinking alcohol, with no effects from sweat; EDA could be measured before and after alcohol intake; and EDA data were available for human skin covered with durable materials. Changes in EDA have been considered to be caused by differences in ion concentrations during transport across the cell membrane, but our experiments using artificial cells revealed that ion concentration was not changed locally by alcohol concentration. It is concluded that drinking alcohol does not cause changes in alcohol concentration by ion transport in the local cell membrane, but has some effect on the transmission system between human cells. However, this requires consideration of alcohol resistance in the human body.

This study clarifies the transmission system between human cells by measuring changes in electroencephalograms before and after drinking alcohol using an electroencephalograph (EEG), and verifies the relationship between EDA and the presence or absence of alcohol resistance by performing a patch test. Changes were observed in the frequency of EEGs before and after drinking alcohol, which suggests that changes in EEGs would have some effect on the transmission system between human cells and cause changes in EDA. In addition, considering the relationship between the patch test and EDA, differences in EDA were small in cases where volunteers were likely to have alcohol resistance, while they were large in cases where volunteers were likely to have no alcohol resistance. Further studies are expected to develop effective driver alcohol detection systems with cost advantages.

INTRODUCTION

Traffic accidents caused by drinking and driving occur around the world, leading to large social and damage costs. Legislation to ban drink-driving is implemented on a mandatory basis in some countries but not in others. In Japan, traffic accidents involving drivers drinking alcohol are often reported, even though drink-driving is restricted. Drivers are sometimes checked by breath alcohol equipment and violent drivers may be arrested, but traffic accidents have never been reduced to zero.

Meanwhile, in the United States, a research partnership between the National Highway Traffic Safety Administration (NHTSA) and motor vehicle manufacturers is attempting to develop a driver alcohol detection system[1)]. Their research and development comprises two approaches, and the results from Phase I were reported at the Enhanced Safety of Vehicles (ESV) conference in 2011. One approach was a method to measure alcohol concentrations in drivers' breath from the ambient air in the vehicle cabin. The other was a direct method to precisely measure blood alcohol concentrations within the first few millimeters of drivers' finger tissues. It may be presumed that the measuring instrumentation and installation would be expensive in both cases.

We have performed fundamental studies in an effort to develop a direct alcohol measurement system as an alternative to the current, simple breath-based measurement system. Our direct method potentially has similar performance to the breath-based system, but it also takes into account the duration of the influence of alcohol and is more widely applicable.

RESULTS ACCOMPLISHED BY THE AUTHORS[2), 3)]

The results from studies by the authors are summarized as follows.

Electrodermal activity (EDA)

When humans drink alcohol, ion movements inside and outside cells cause a variation in EDA. If values of the action potential are below a particular threshold, repeated polarization occurs through ion movement inside and outside cells and the measured values of EDA will fluctuate. When the value of the action potential is above the threshold, the value of the electrical potential becomes steady and the EDA becomes comparatively steady. In most cases, the electrical potential difference caused by an action potential is above a threshold in an active phase. Measurement methods exist for inside of cells (endosomatic) and outside of cells (exosomatic). Direct current and alternating current measuring methods are available for exosomatic. Table 1 provides representative measuring methods[4)]. The contact method may apply a weak alternating current, which is used, for example, in lie detection equipment. Alternatively, a contact method can use a direct current that measures differences in electrical potentials between two electrodes, a reference electrode and a measuring electrode, to measure EDA. In this study, the contact method using direct current was applied.

Table 1 Electrodermal activity measurement methods[4)]

Recording	Endosomatic	Exosomatic	
Action current	-	A direct current*	An alternating current
Units	Skin potential	Skin resistance, Skin conductivity	Skin impedance, Skin admittance

* used by the authors

Membrane potential[4)]

When action potentials created by differences in potentials are below the threshold, the following formula can be applied:

$$V_x = V_0 e^{-x/\lambda} \quad (1)$$

Here, V_0 is the signal size at an original point,

V_x is the signal size at a distance, and

λ is a constant of length.

Because the phenomena are modeled exponentially and are repeated, they take the form of a vibrating system with decay. Meanwhile, it is known that an action potential becomes stable when it is above the threshold. Thus, the effect on electric potential by action potentials is transmitted along the axis of a cylinder. This condition can be identified from the results in the experiments.

To clarify the mechanism of internal or external ion flows near the cell membrane, the distribution of ion concentration was observed by an ion probe and a fluorescence microscope before and after alcohol intake, as described below. The results indicate that fluctuations in EDA caused by drinking alcohol could be concluded to occur through action potentials transmitted along an axial cylinder from the brain, because there was no observable change in the ion concentration distribution in artificial cells. Note that this is a result obtained using artificial cells.

Measurement system[4)]

Generally, a measurement system uses a survey electrode placed on the palm, which has many sweat glands, and a reference electrode is placed on the forearm, which has fewer sweat glands. Previous measuring systems consisted of electrodes placed on the forearm and palm, an amplifier, instruments for measuring differences in potentials and a computer for built-in data processing. Figure 1 shows a schematic for such a measurement system.

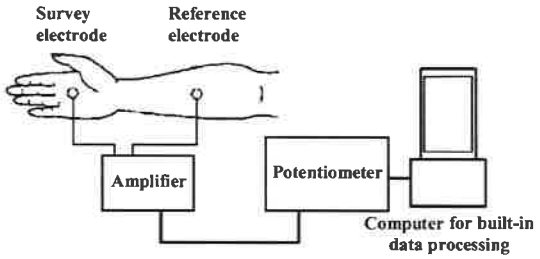

Fig. 1 Schematic of a Measurement System

The types and positions of the two electrodes are typically arranged for specific purposes, as described in the following.

Type of electrodes[4)]

Various types of electrodes exist. In this study, commercially available Vitrode Bs Ag/AgCl paste with a Cotton Tape Disposable Electrode for ECG Monitoring (Nihon Kohden Corporation) was used. This ECG electrode is on the market as a cardiac electrogram monitor and is in general use. The electrode plays the role of a transducer to transform ionic current into an electron current.

Position of electrodes, distance between electrodes, and how to hold the steering wheel[2)]

Although normal practice is to locate the electrodes on the palm and forearm, when starting an engine before driving a vehicle, the driver often pinches an ignition key between the fingers and holds the steering wheel with the palm and fingers. Therefore, experiments were conducted focusing on the positions of the electrodes and the distance between them. First, electrodes were placed on the center of the palm as a reference electrode and on the forearm for measurement. Second, assuming the normal situation for holding the steering wheel, the EDA was measured by electrodes placed on the palm and each of the five fingers. Third, assuming the driver holds an ignition key, the electrodes were placed on the thumb and forefinger. The results measured using the steering wheel and ignition key electrode placements tended to be similar to the palm and forearm placement, confirming that EDA could be measured by electrodes placed with a certain distance between them.

In addition, the configuration of fingers holding a pole was investigated to be sure that the EDA could be measured on a steering wheel. Variations of the orientation of holding were investigated using a straight round bar, with infinite curvature, and a round bar with finite curvature. The result showed that both orientations were similar. In other words, the orientation of the fingers was not affected significantly by the shape of the object being held.

Overall, the two cases of electrode placements for inserting an ignition key and placing the hands on the steering wheel produced similar EDA measurements.

EDA of mice before and after alcohol injection[3)]

An experiment was performed to investigate the EDA of mice that had alcohol injected into their bodies, using the measurement equipment described above with disposable electrodes. Mice do not sweat from their forepaws or hind paws but electrodes placed on the foreleg and hind leg using modified tweezers were found to be effective for obtaining stability data. Figure 2 shows the fluctuations in EDA with time when mice ingested 0.2 cc alcohol solution containing 60% ethanol for mice that were intoxicated, in a coma, or dead. The value of the electrode signal remained stable prior to alcohol intake, but fluctuated after alcohol intake and finally reached zero. Mice that did not sweat at their extremities were used to avoid the effects of sweat, which are known to affect EDA values. The results show that EDA in mice with no sweating effects differed greatly before and after alcohol intake.

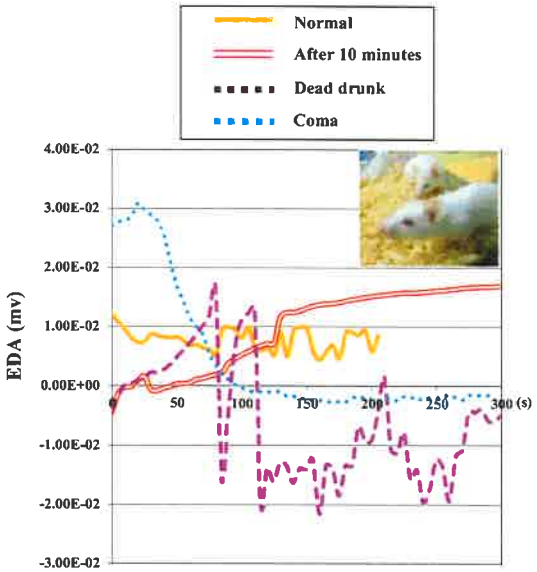

Fig. 2 Relation between EDA and time before and after alcohol intake using mice[3)]

Comparison with the breath alcohol concentration detector system

Values from two types of breath-based measurement system available on the market were compared with the EDA method. The first breath-based system was a blowing type (Urban system CA20000, 1 mg/l) and the second type used breathing into a nozzle (SOCIAC-X , 05 mg/l). Table 2 shows the experimental conditions. Measurements were carried out not only of breath alcohol concentration but also of EDA simultaneously. As a simple countermeasure to the direct influence of sweat, electrodes wrapped with thin plastic wrap were used to measure the EDA. The results are shown in Figure 3. The results confirmed that this simple method was effective for measuring EDA.

Table 2 Experimental conditions

Test No.	Experimental conditions	
1	Before drinking	
	Drinking: 350 ml with 5% alcohol x two bottles	
2	After drinking the first bottle	In 2 minutes after 1 minute passed, the EDA was measured then the breath alcohol concentration was measured
3	After drinking the second bottle	In 2 minutes after 1 minute passed, the EDA was measured then the breath alcohol concentration was measured
4	After 12 minutes passed after drinking the second bottle	

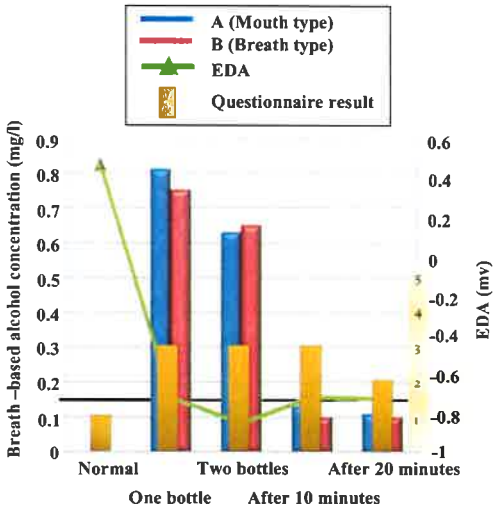

Fig. 3 EDA and Breath-based alcohol concentration as a function of time using human participants[3)]

Comparison with other data

A comparison between breath-based alcohol concentrations and EDA is shown in Figure 4. The breath-based measurement systems provide high values immediately after drinking, but the values drop rapidly and return to normal levels. On the other hand, although the EDA measurement depended on alcohol concentration, it took 8 hours for values to return to normal levels. This was verified by questionnaires to participants. Thus, breath-based measurement systems may sometimes not provide values that match feelings of intoxication.

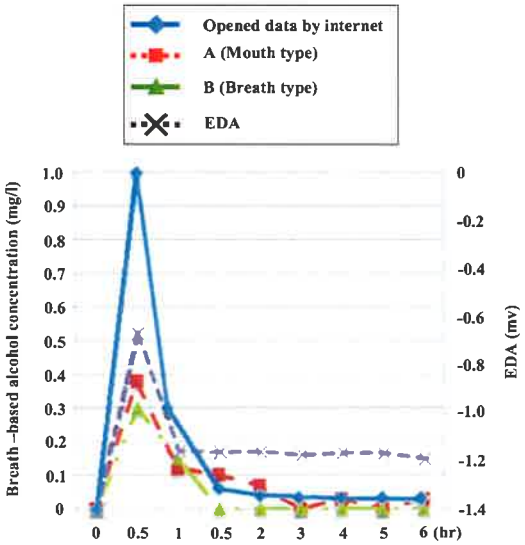

Fig. 4 Comparison between the breath-based alcohol concentration and EDA detection methods with time using human participants[3)]

Artificial cell membrane and fluorescent ion probe experiments

Using an ion probe (Fura 2) that can detect many ions involved in the transmission of information in cells, artificial cells (mouse epidermal keratinocyte lines Pam 212) were observed before and after alcohol intake. The epi-illumination fluorescence microscope was used for observation. Ca was ingested by the ion probe and there was no change seen in the distribution of Ca uptake by the ion probe before and after alcohol intake.

Data processing

It was revealed by absolute level, amplitude, wavelength, tilt, and the filtering process of waves, along with analyses before and after drinking, that drinking alcohol could be detected in 70% of participants[3)].

To clarify the local mechanism of EDA, the Ca ion concentration was analyzed using artificial cells and fluorescence microscopy. As a result, no local or distinguishing changes were observed. It is concluded that EDA fluctuations are not caused by a change in ion concentration in the local cell membrane. That is, we speculate that after drinking alcohol, a human body suffers effects not from changes in ion concentration in the local and terminal cell membrane but from time differences in commands and transmittance from brain cells.

INVESTIGATION OF PRESENT STUDY

To clarify the commands and transmittance from brain cells, measurement of electroencephalograms were investigated before and after drinking. In addition, simple patch tests were conducted for participants to examine alcohol tolerance, making it possible to distinguish between persons with high and low tolerances for alcohol by investigating the correlation between electroencephalograms and EDA. The results show that there were differences between alpha and theta waves, and that participants had two overall tendencies, despite individual variations.

Method

EDA, electroencephalogram and patch tests were performed.

Disposable electrodes were used to measure EDA, along with a simple device for measuring electroencephalograms. The reference electrode was placed on the ear lobe and the sensor band placed on the forehead.

An electroencephalograph (EEG: FM-717) with dedicated software Pullax II was used. Table 3 shows the relationship between available waves and frequency, and the features of each wave.

Table 3 Specifications of electroencephalograph and conditions

Name	Frequency (Hz)	Conditions in a human body
θ	4~7	Often detected in REM sleep
α1	7~9	Feeling drowsy, almost falling asleep
α2	9~11	Relax, high degree of concentration
α3	11~13	Low degree of concentration, calm down
β	13~30	Detected by electroencephalograms in normal conditions

The results in patch tests depend on the amounts of enzyme broken down by the acetaldehyde produced when alcohol is degraded. The determination is shown in Table 4. Rubbing alcohol with 50% isopropanol as a reagent solution, adhesive plasters, and medical gauzes were used.

Table 4 Results and determinations in patch tests

No difference on the skin	→ ALDH2 activate form
Getting red on the skin	→ ALDH2 Low active form

The volunteers were 14 people in total, comprising females and males in their 20s to 30s. Beforehand, they have been provided explanations with materials describing the purpose and nature of the experiments and they then agreed to participate.

Results

EDA

Representative results are shown in Figures 5 and 6. The results show that the wave patterns of EDA after drinking alcohol can change enormously or only slightly, similar to results in previous experiments.

Results from the electroencephalograph

The chart indicates the ratio of electroencephalograms after drinking alcohol for an electroencephalogram in which each frequency level in the normal condition is given the value of one.

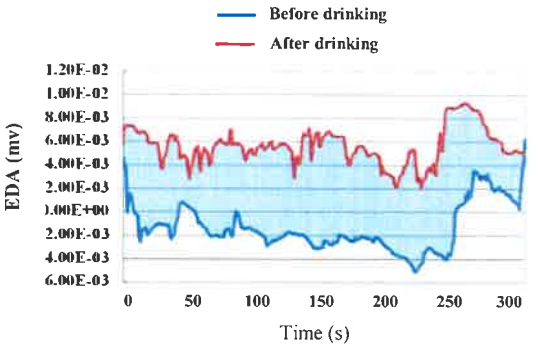

Fig. 5 Changes in EDA after drinking alcohol (example 1)

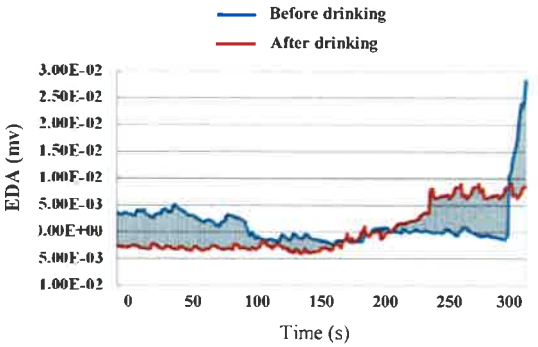

Fig. 6 Changes in EDA after drinking alcohol (example 2)

Three representative examples of results from the electroencephalograph are shown in Figures 7–9. Figure 7 indicates low frequencies increase compared with normal conditions (hereafter referred to as type A). Figure 8 indicates that high-frequency bands increase compared with normal conditions (referred to as type B). Figure 9 indicates that values change randomly compared with normal conditions (referred to as type C).

In any case, changes in the electroencephalograms after drinking alcohol could be measured, from which it can be concluded that alcohol affects the electroencephalograms. Additionally, questionnaires were completed by participants. Participants who answered "feeling sleepy" are often categorized to follow the data in Figure 7 (low frequencies increase: type A), while participants who answered "feeling cheerful or joyful" often belong to Figure 8 (high-frequency bands increase: type B).

Therefore, the results of electroencephalograms corresponded approximately to the results of the questionnaires. Thus, electroencephalograms biased

toward low frequencies were associated with feeling sleepy, but conversely those biased toward high frequencies were associated with feeling cheerful.

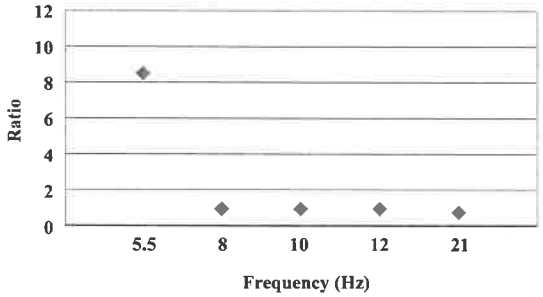

Fig. 7 Results from the electroencephalograph: low-frequency bands get higher (type A)

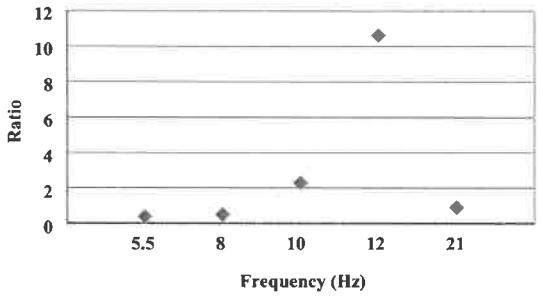

Fig. 8 Results from the electroencephalograph: high-frequency bands get higher (type B)

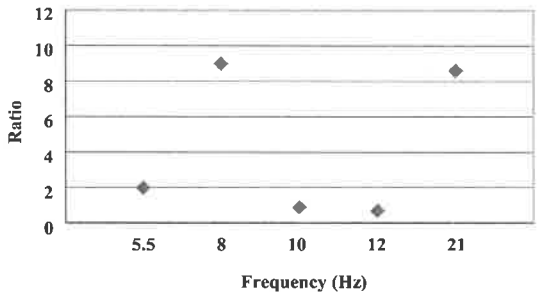

Fig. 9 Results from the electroencephalograph; there is no discernible trend (type C)

Results in patch tests

Proceeding in accordance with the patch tests, Table 5 shows a summary of the results from the patch tests. The results can be classified approximately into two groups, in which changes are shown in some persons but not in others.

Table 5 Summary of results in the patch test

Skin color	Human subjects	Numbers
No change	Having alcohol resistance	6/14
Turning red extremely	Having no alcohol resistance	8/14

Additional experiments

With the objective of putting this method into practical use in mind, additional experiments were performed. When electrodes are placed on an ignition key, any obstacle between the ignition key and the fingers may interfere with the measurement. Therefore, this experiment was conducted by supposing that obstacles with thickness might be inserted between the electrodes. Several materials of different thickness were tested. The results are shown in Figure 10. Papers with thickness equal to or less than approximately 0.8 mm could be measured as Figure 10 shows. However, there were considerable differences between 0.08 and 0.3 mm, and this requires further experiments.

This experiment was also conducted under the condition of wrapping of electrodes, providing further results for samples involving the effects of sweat on electrodes. From a different point of view, electrodes acted as a transducer, in that they converted ion-exchange phenomena to electron-exchange phenomena, a result that changes the role of the electrode. However, this degree of accuracy was not required here.

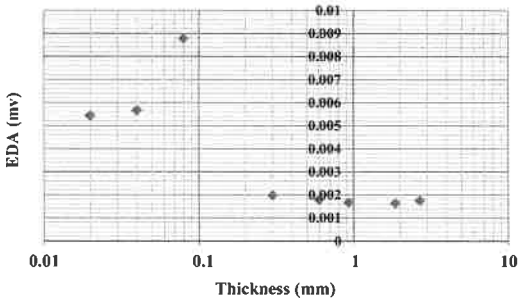

Fig. 10 Changes in EDA by insertion of obstacles

Electroencephalograms can be divided into three types on the basis of clear differences in the results before and after drinking alcohol, as indicated in the electroencephalogram measurements. It was clarified that the first case of a small change in low-frequency content indicated a feeling of sleepiness; the second case associated changes in high-frequency content with a feeling of cheerfulness; and in the third case,

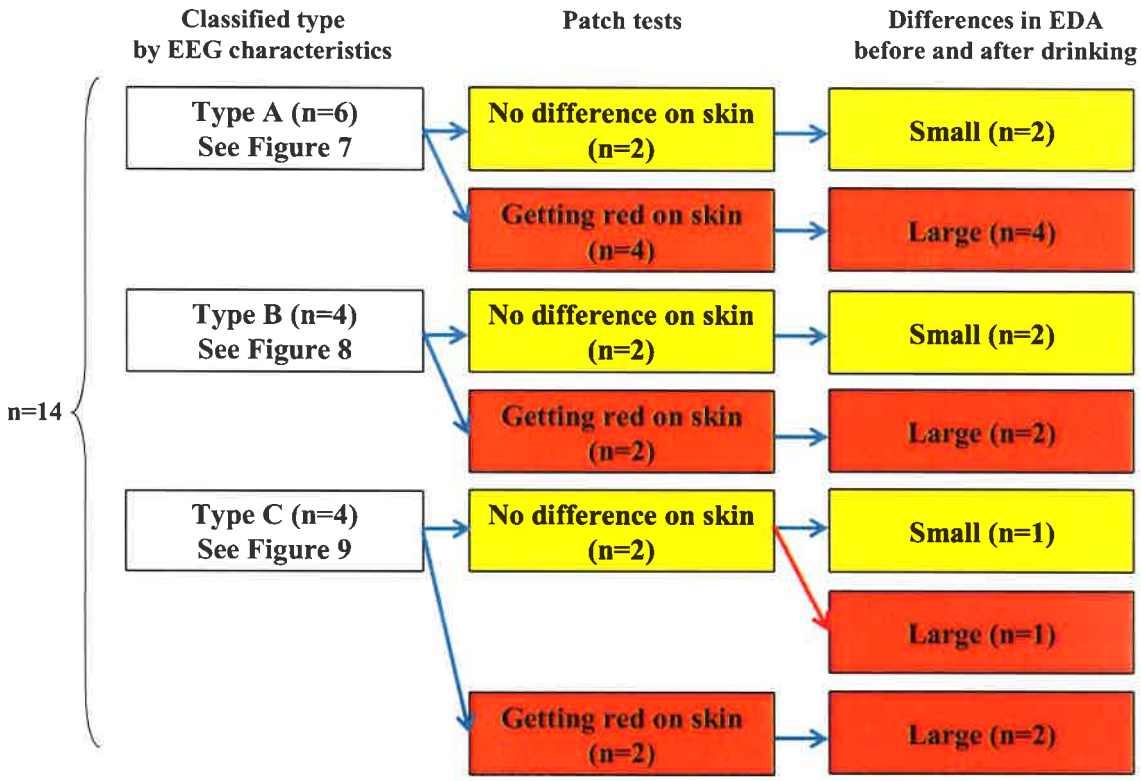

Fig. 11 Correlative relationship of EDA arranged based on the results from the patch test

both the above cases were mixed. Differences in the changes to EDA corresponding to the three types of electroencephalograms were not validated in this experiment.

In addition, the results from the above experiments for EDA were arranged based on the patch tests. Figure 11 shows results classified by the presence (getting red on the skin) or absence of a response (no difference on the skin) in the patch tests. Where there was getting red on the skin in the patch test result, marked differences in EDA were observed before and after drinking alcohol, while in the no difference on the skin in the patch test result, there were only small differences in EDA before and after drinking alcohol. Similar tendencies were observed in each classified type of EEG characteristics shown in Figures 7, 8 and 9.

DISCUSSION

We have clarified the mechanism of EDA, performing experiments using artificial cells, assuming that local ion exchange could result in fluctuations in EDA when drinking alcohol. The reported results were from experiments using artificial, rather than real cells. This study was based on the supposition that fluctuations in EDA upon consumption of alcohol would be caused not by the flow of ions inside and outside the local cell membrane but by nerve cells. It is believed that the channels and pumps in human cells are opened and closed by the brain's chain-of-command. Therefore, electroencephalograms were measured, and the results confirmed that fluctuations in the frequency band of electroencephalograms indicated both changes in the transmission system and EDA simultaneously. The channels and pumps transporting ions across the cell membrane are opened and closed by the brain's chain-of-command, while alcohol is absorbed or blended into the blood in the human body. As a result, the chain-of-command controlling the internal and external cell membranes becomes disordered, and ion concentrations change, finally causing EDA to change, confirming the above mechanism.

CONCLUSIONS

Fluctuations in electrodermal activity (EDA) before and after drinking alcohol are summarized as follows:

1. Electroencephalograms can be divided into three types: low frequency increases; high-frequency band increases; and no trends.
2. Large or small changes in EDA could be observed and the data range was sufficient for measurement.
3. The patch test is a simple method for examining alcohol tolerance.
4. The results from the patch tests corresponded to those from EDA experiments. In the presence of a response in the patch test, relative values of EDA become large. On the contrary, in the absence of a response in the patch test, differences between relative values become small.
5. EDA is produced by differences in ion concentration inside and outside the cell membrane, which can be considered to be caused not by local changes in ion concentration but by changes in the transmission of the brain's chain-of-command. As a result, it can also be presumed to have effects on EDA.

FUTURE WORKS

In the present study, it was clear that, knowing the EDA of each person under normal conditions, the relative changes from the initial values of EDA made it possible to detect alcohol. This experiment was performed with Japanese people. In the future, the reliability of data must be improved if the three test methods—EDA, electroencephalograms, and patch tests—are conducted for people of other nationalities. It is believed that this method will comprise an effective sensing system, through simplification of the sensing measurement system itself or reduction in cost.

ACKNOWLEDGEMENTS

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