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A Mental Health Database Creation Method with Neuroscience-Inspired Search Functions

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Abstract. Mental health, an essential factor for maintaining a high quality of life, is determined by one's nutritional, physical, and psychological situations. Since mental health is influenced by multiple factors, a multidisciplinary approach is effective. Due to the complexity of this mechanism, most non-specialists have little knowledge and access to the related information. There are multiple factors that influence one's mental health, such as nutrition, physical activities, daily habits, and personal cognitive characteristics. Because of this complexity, it can be hard for non-specialists to find and implement appropriate methods for improving their mental health. This paper presents the 2-Phase Correlation Computing method for interpreting the characteristics of each emotion/mental state, nutrients, exercises, life habits with a vector space. The vector space reflects the roles of neurotransmitters. The 2-Phase Correlation Computing extracts the information expected to be most relevant to the user's request. In this method, expert knowledge, characteristics of emotions, and mental states are defined in the "Requests" Matrix, and each stimulus into "Nutrients", "Exercises", and "Life Habits" Matrixes. "Nutrients", "Exercises", and "Life Habits" are expressed and computed to as "Stimuli". In short, this method introduces logos to the chaotic world of decision making in mental health.

Keywords. Mental health, combinatorial vector, 2-Phase Correlation Computing, neurotransmitters

1. Introduction

Mental health is a significantly important factor in the quality of life. It strongly affects one's performance and subjective well-being. In 2015, the World Health Organization announced the Sustainable Development Goals, which are "a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity" [1]. There are 17 goals, and Goal3; Good Health and Well-being is one of them. The World Health Organization has stated the importance of promoting mental health worldwide as well [2].

In this paper, we apply expert knowledge of mental health to our 2-Phase Correlation Computing. The fields of expert knowledge are neuroscience [3], psychiatry, and nutrition science [4]. We also present a knowledge base and database for realizing a

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comprehensive ranking of various types of mental health solutions. The concept of the Mathematical Model of Meaning was applied for creating the metadata [5,6]. In the database, there are 3 types of mental health solutions based on expert knowledge, "Nutrients", "Exercises", and "Life Habits". Based on neuroscience knowledge, we created the "Requests" matrix that enables comprehensive solution discovery from these multidisciplinary methods. The vector spaces of each matrix realize a semantic search function, expressing characteristics of the mental state numerically. The vector spaces are created based on previous studies showing the relations of stimuli and neurotransmitters. The solution ranking is based on scores that reflect the expected effectiveness of the information.

Mental disorders are caused by brain dysfunction, which is triggered by the imbalance of neurotransmitters in the brain [3,4,7]. The brain can function normally if their balance is restored. Internal medicine has been used for this purpose. Selective Serotonin Reuptake Inhibitors (SSRIs) such as Paxil, Prozac, and Zoloft suppress depression symptoms by eliminating the serotonin deficiency in the brain. Benzodiazepine anti-anxiety agents such as Librium, Barium, and Xanax inhibit excessive excitement of the brain by promoting the function of gamma-aminobutyric acid (GABA) in the brain. GABA is an inhibitory neurotransmitter [4].

The effectiveness of medicine has been proved. However, they have serious side-effects, and long-term use develops tolerance, which can lead to addiction. To treat mental disorders, we have to restore the balance of neurotransmitters, and there are methods to realize this naturally without internal medicine [4].

Orthomolecular medicine describes the practice of treating and preventing diseases by providing the body with optimal amounts of endogenous and naturally occurring substances such as vitamins, minerals, and amino acids. Within orthomolecular medicine, there is orthomolecular psychiatry, which is the use of orthomolecular medicine for treating mental disorders [8].

Neuroscience is the scientific study of the nervous system. Numerous researches have proved the effectiveness of exercising in balancing brain functions, including neurotransmitters. The effectiveness of exercising in learning, managing stress, anxiety, depression, attention deficit disorder, addiction, hormonal changes, and aging has been proved [6]. There are also other life habits and activities that affect neurotransmitter secretion, such as insolation, meditation, taking naps, setting a deadline, and making a new challenge [3].

Many technologies support the adoption of each type of solution in daily life. For example, many nutrition management applications, exercise supporting applications, and habit tracking applications have been developed. However, a holistic approach that restores the balance of the whole body is more effective for the improvement of a condition. This is difficult because of the complexity of related information. There has not been a calculation method that ranks the effectiveness of information on nutrients, exercises, and life habits comprehensively.

This research realizes a novel calculation method that reflects the functions of neurotransmitters and provides solution ranking that helps the user adopt a holistic approach.

2. The Methodology of Database Creation

There are three steps for creating the database. Firstly, a vector space that reflects moods and mental states is created. This is the "Requests" Matrix. Secondly, vector spaces that reflect the effects of the stimulus on the mental state are created. They are the "Nutrients", "Exercises", and "Life Habits" Matrixes. Thirdly, a vector space that reflects the contents of websites that include information about stimuli is created. This is the "URLs" Matrix. The basic rules of this database are as follows:

2.1. Vector Space Structure

2.1.1. Origin Point

The origin point in each stimulus matrix is where the stimulus has no significant relation with the neurotransmitter.

2.1.2. Vector Normalization of Correlation Computing for Mental Health Analysis

The goal of the vector normalization in this research is to express the actual mental health situation and make it possible to apply correlation computing to the normalized vector. In this method, 2-norm is used for the normalization with the minimum value, -2, and the maximum value 2.

The method of creating stimuli vectors is inspired by concepts of neuroscience, especially the roles of neurotransmitters on mental health. The value 0 means no significant relation. Negative values mean negative relation in mental health situations, and positive values mean positive relation. One key aspect of this research is to create a method of this normalization for neurotransmitter levels associated with different mental conditions. This realizes a semantic space reflecting expert knowledge such as neuroscience, medicine, and nutritional science.

The distance computing in this method consists of two phases. The first phase is calculating the inner product between the assumed neurotransmitter balance of particular mental states and stimuli. The second phase is calculating the inner product of information contained in websites and stimuli necessary for achieving the selected request. The value of this method is that it combines findings of various fields related to neurotransmitters and utilizes this metadata to find valuable information.

2.2. System Structure

A processing method with two inner product calculations is conducted in our system, which we refer to as "*2-Phase Correlation Computing*." Figure 1 shows the process of 2-Phase Correlation Computing in the system. The final calculation result of this process shows the scores of website URLs containing relevant information on effective solutions.

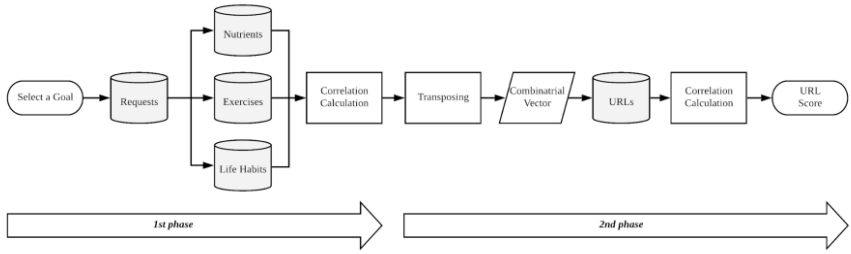

Figure 1. The Algorithm of 2-Phase Correlation Computing

As an input, the goal of the user is selected as a request. The "Requests" matrix consists of relations that are vectors reflecting the characteristics of each mental state. Characteristics of the mental states were numerically defined based on neuroscience knowledge and the concept of the Mathematical Model of Meaning (MMM) [5]. Semantic Search for finding personalized mental health information is realized with this method.

Next, the inner product of the requested mental state and each stimuli matrix ("Nutrients", "Exercises", and "Life Habits") is calculated. The calculation results are combined together and are transposed to form the combinatorial vector. The score of this calculation can be used to extract General Solutions. The first phase ends here.

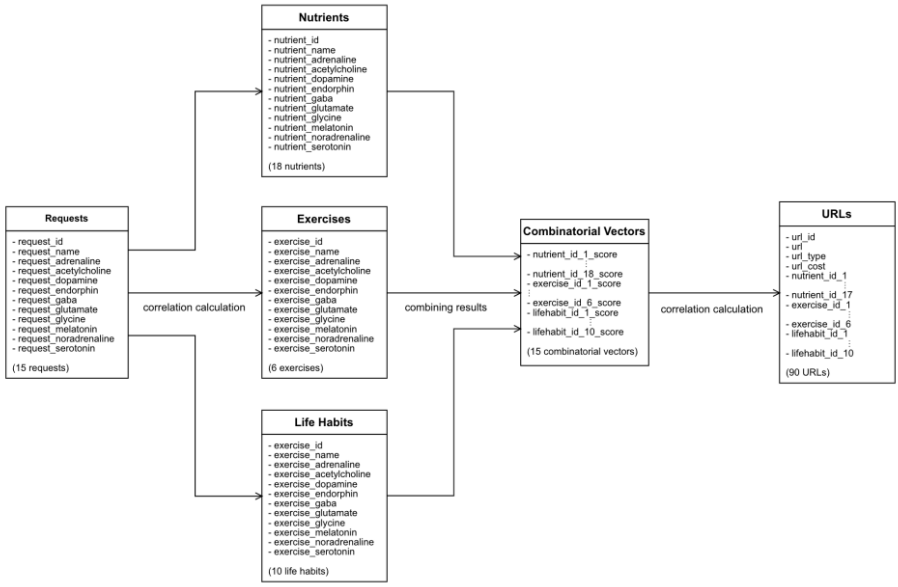

Figure 2. Database Structure

Finally, the inner product of the combinatorial vector and "URLs" matrix is calculated. The "URLs" matrix consists of vectors reflecting the information content of each website. The URLs include general information, service information, products, and instructions. Various kinds of media that help the user understand or implement each solution (stimuli) have been selected. The correlation value is the score. Finally, based

on the score, the website URLs expected to be effective in achieving the selected request are shown as a ranking.

Figure 2 shows the structure of each matrix. The method of vector creation in each matrix is explained after Figure 2.

2.2.1. The "Requests" Matrix

The Requests matrix is meta-data that corresponds to the relation of each mental state and neurotransmitters that cause it. The relation is defined based on descriptions in a publication on neuroscience [3].

The Requests matrix consists of 10 dimensions. They are adrenaline, acetylcholine, dopamine, endorphin, gamma-aminobutyric acid (GABA), glutamine, glycine, melatonin, noradrenaline, and serotonin. "0" means that the state has no relation with the secretion of the corresponding neurotransmitter. "1" means that the state has a relation with the secretion of the corresponding neurotransmitter, and "2" means that it has a significant correlation. "–1" means that it has a negative correlation with the secretion of the corresponding neurotransmitter. These values are interpretations of statements from expert knowledge on neuroscience [3]. "Defensive motivation" is a motivation triggered by the defensive system of the brain, and "intrinsic motivation" is a motivation that occurs as a result of the reward system of the brain. An example of a Semantic Search with "intrinsic motivation" as a request is shown in chapter 4.

2.2.2. The "Nutrients", "Exercise", and "Life Habits" Matrixes (Stimuli Matrixes)

Each stimulus matrix consists of 10 dimensions. They are identical to the dimensions of the "Requests" matrix. The values reflect the relation of each stimulus and the secretion of neurotransmitters. Vector values of nutrients [4,10,11,12], exercises [7], and life habits [3,13,14,15,16] are determined based on previous studies.

In the "Exercises" matrix, based on a control experiment that studied the effect of exercising on depression patients, the exercise "aerobics (high dose)" means that the sum of the kilocalories consumed in a week is $[17.6\times (kilogram\ weight)]$. The exercise named "aerobics (low dose)" means that the sum of the kilocalories consumed in a week is $[17.6\times (kilogram\ weight) \times 0.45]$. Intense exercise that raises the heart rate is proved to be more effective in preventing anxiety [7].

2.2.3. The "URLs" Matrix

URL matrix is a metadata of the websites that would be shown as suggestions. 90 websites are registered. Websites that include information on the stimuli were chosen manually. The URL matrix has the information on each stimulus in "Nutrients", "Exercises" and "Life Habits". Various types of media are included so that the user can choose based on his/her needs. This matrix is a meta-data showing what stimuli data the websites include. The cost is also included. The type "g-information" means that the website has detailed information on the stimulus itself, and "s-information" means that the website has information on services that realize the acquisition of the stimulus.

For example, if the user is not sure what kind of media would be useful for him/her but prefers strongly related and affordable information, results excluding the types "product" and "s-information" can be extracted.

2.3. The 2-Phase Correlation Computing

The first phase and the second phase are both correlation calculations. The first phase has 10 factors (adrenaline, acetylcholine, dopamine, endorphin, gamma-aminobutyric acid, glutamine, glycine, melatonin, noradrenaline, and serotonin). The second phase can be freely determined by the preference of the URL or user's context.

In the second phase, the combinatorial vector that includes all the inner product calculation results of the selected request and each stimulus is generated. This realizes a calculation process that can evaluate the expected effectiveness of different types of websites containing different types of stimuli all at once. The mathematical expression of the process is as shown below.

First, the values in each matrix are converted into a numerical matrix as follows. The Request matrix, Nutrients matrix, Exercise matrix, and Life Habits matrix are each expressed as R, N, E, and L. Eq. (1), (2), (3), and (4) are the corresponding equations.

$$R = \left((r_{(1,1)} \cdots r_{(1,10)}),\ \cdots, (r_{(15,1)} \cdots r_{(15,10)})\right) \tag{1}$$

$$N = \left((s_{(1,1)} \cdots n_{(1,10)}),\ \cdots, (s_{(18,1)} \cdots s_{(18,10)})\right) \tag{2}$$

$$E = \left((s_{(1,1)} \cdots s_{(1,10)}),\ \cdots, (s_{(6,1)} \cdots s_{(6,10)})\right) \tag{3}$$

$$L = \left((s_{(1,1)} \cdots s_{(1,10)}),\ \cdots, (s_{(10,1)} \cdots s_{(10,10)})\right) \tag{4}$$

The first row of the URL matrix consists of all the stimuli from Nutrients, Exercises, and Life Habits. The stimuli names listed in columns are converted into a row. The order is identical. The URL matrix is expressed as U, as shown in Eq. (5).

$$U = \left((u_{(1,1)} \cdots u_{(1,34)}),\ \cdots, (u_{(90,1)} \cdots u_{(90,34)})\right) \tag{5}$$

Second, the inner product of request and each stimulus is calculated, as shown in Eq. (6). The first phase ends here.

$$a = R \cdot N,\ b = R \cdot E,\ c = R \cdot L \tag{6}$$

Third, the results of this calculation are combined into one matrix, as shown in Eq. (7). The order is $a, b,$ and finally c. Next, this matrix is transposed. This is the combinatorial vector. The order of the values in the combinatorial vector is identical to the order of all the stimuli in the URL matrix. The combinatorial vector is expressed as V, as shown in Eq. (8).

$$a \oplus b \oplus c = \left((a_1,\ a_{18}), \cdots, (b_1 \cdots b_6), \cdots, (c_1 \cdots c_{10})\right) \tag{7}$$

$$V = \left((a_1 \cdots a_{18}),\ (b_1 \cdots b_6),\ (c_1 \cdots c_{10})\right) \tag{8}$$

Finally, the inner product of the combinatorial vector and URL Matrix is calculated, as shown in Eq. (9). The URL score is expressed as Z.

$$Z = V \cdot U \tag{9}$$

3. Prototype System Implementation

3.1. Semantic Search for "Intrinsic Motivation"

We have implemented the experimental system by using MATLAB [17]. The inner-product values in the combinatorial vector show the effectiveness of each stimulus. Effective means that they are expected to lead to the mental state selected by the user. This is defined as the score of General Solutions for the request. General Solutions can be calculated after the first-phase correlation computing, as shown in Figure 3. In this case, "Intrinsic Motivation" is selected as a goal. The stimuli with a score higher than 0 are considered as General Solutions. The stimuli with a score lower than 0 are expected to cause the opposite effect. General Solutions show all the stimuli except those with score 0.

These are the stimuli expected to be effective in achieving "intrinsic motivation". In this case, "aerobics (high dose)" was ranked with the highest score 2. This result matches with the findings that such exercise highly promotes motivation and prevents anxiety and depression [7]. There were 14 other stimuli with score 1. They also matched with the expert knowledge included in the stimuli matrixes. In total, there were 3 exercises, 10 nutrients, and 2 life habits.

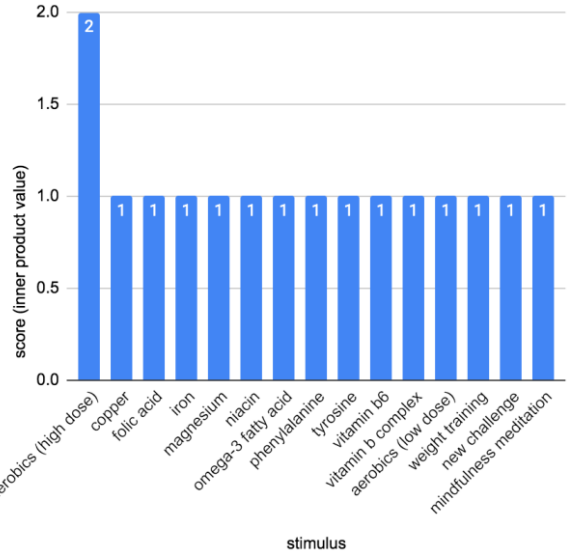

Figure 3. General Solutions for Intrinsic Motivation Ordered by Score (Inner Product Value)

The score indicates that a high-dose aerobic exercise has the most significant influence in achieving this goal. This is because high-dose aerobic exercise influences more neurotransmitters than the other stimuli. Stimuli with score 1 trigger the production of a single neurotransmitter in the brain. This result shows that the expert knowledge included in the three stimuli matrixes are effectively integrated and can be extracted according to the user's request.

As a result of the second-phase correlation computing, website URLs containing information on general solutions, and their scores are extracted. The score is defined as the inner-product value. Due to this nature, websites that include information on multiple stimuli tend to have higher results. The distribution of their score is shown in Figure 4.

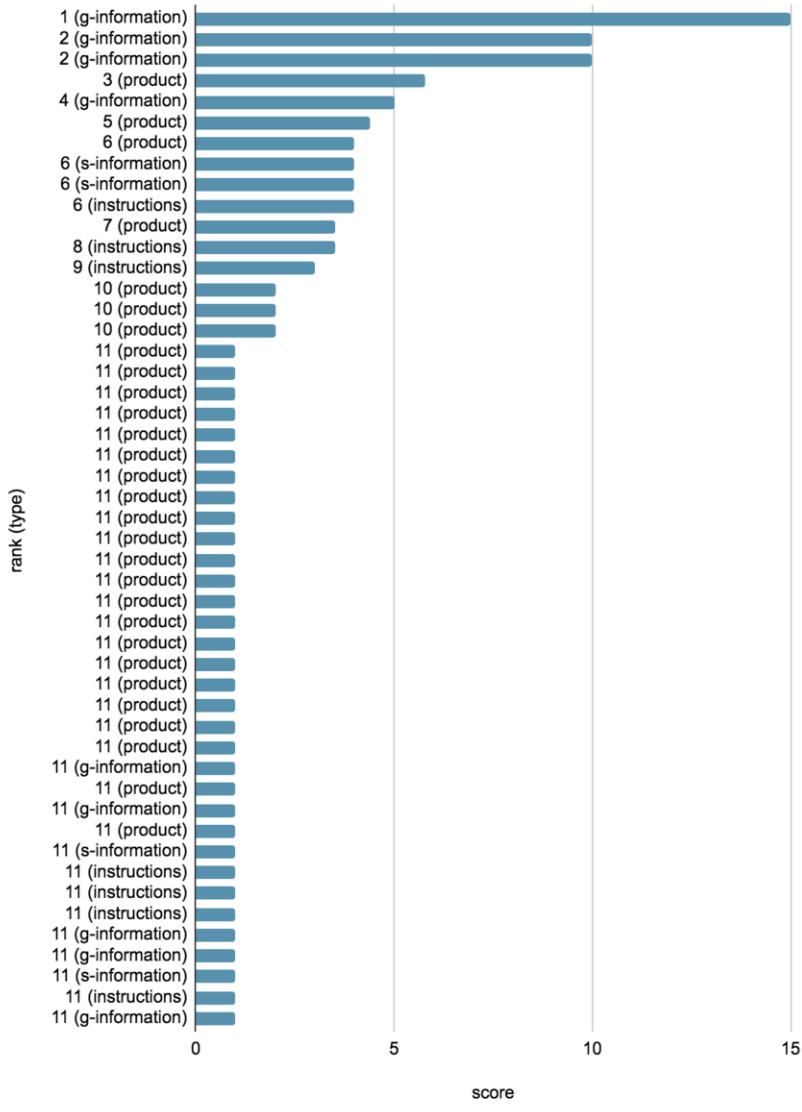

Figure 4. URL Score Distribution for Intrinsic Motivation (Ranking Ordered by Inner Product Value)

By accessing any website with scores higher than 0, the user can acquire detailed information on effective stimuli or purchase an effective product. The results with score 1 are websites with information or an online shop page for 1 stimulus. They are simpler and more targeted.

For example, all information on effective stimuli except "new challenge" (a method to make a new challenge in life) can be found on the website with the highest score, which is an evidence-based healthcare information website. If the user wishes to acquire information, he/she can access the webpage ranked no.11 with score 1, which is an article explaining how to challenge yourself by starting a new activity.

There are many patterns of combining information for the user. The user can either start with accessing websites with relatively higher scores, or filter results based on their preferences. They can be filtered by stimuli types, information types, or cost.

Next, with an assumption that the user only wishes to find instructions on acquiring the effective stimuli, the result can be filtered, as shown in Table 1. The webpage ranked no.1 has information on high-dose aerobics, low-dose aerobics, and weight training. Thus, a wider variety of information can contribute to a higher score.

The websites with lower scores have information on fewer stimuli. However, it can mean their content is more concise if the score is bigger than 1. Using information with a score higher than 1, the user can implement actions that regulate their neurotransmitter levels to achieve the goal state.

Table 1. Filtered Website Ranking for Intrinsic Motivation

rank	contents of the website	score (inner product)	type
1	bodybuilding instructions (both exercises and nutrition)	4	instructions
2	HIIT exercise video	3.5	instructions
3	cardio exercise video	3	instructions
4	squatting exercise video	1	instructions
4	instructions on starting a new activity	1	instructions
4	instructions on choosing a new hobby	1	instructions
4	mindfulness meditation instruction video	1	instructions

3.2. Semantic Search for "Calmness"

When "calmness" is the selected goal, there were 27 general solutions calculated. They are shown in Figure 5. Unlike the previous case with the goal "intrinsic motivation", there are 9 general solutions with negative scores. This indicates that these stimuli lead to the opposite state of "calmness".

Calmness is promoted when inhibitory neurotransmitters are produced in the brain. The nutrients phenylalanine and tyrosine are necessary for the production of adrenaline and noradrenaline, which are excitatory neurotransmitters. They lead to excitement and agitation, which are the opposite states of calmness. Weight training, setting a deadline, and excess copper intake also promotes this. The nutrients folic acid, iron, and niacin act as coenzymes when producing the excitatory neurotransmitters. However, without tyrosine and phenylalanine, they have a neutral effect on neurotransmitters. There should be a function to exclude such nutrients.

In the case of "calmness", the solution with the highest score was mindfulness meditation. It promotes the synthesis of neurotransmitters that lead to calmness and prevents the synthesis of neurotransmitters that lead to the opposite state [13,14,15,16].

As in the case with the Semantic Search for intrinsic motivation, when fewer neurotransmitters are associated with the stimulus, the score is lower. Again, stimuli shown matched with the expert knowledge included in the stimuli matrixes. The scores calculated with 2-Phase Correlation Computing can be used for discovering priority in mental health management and preventing non-favorable stimuli.

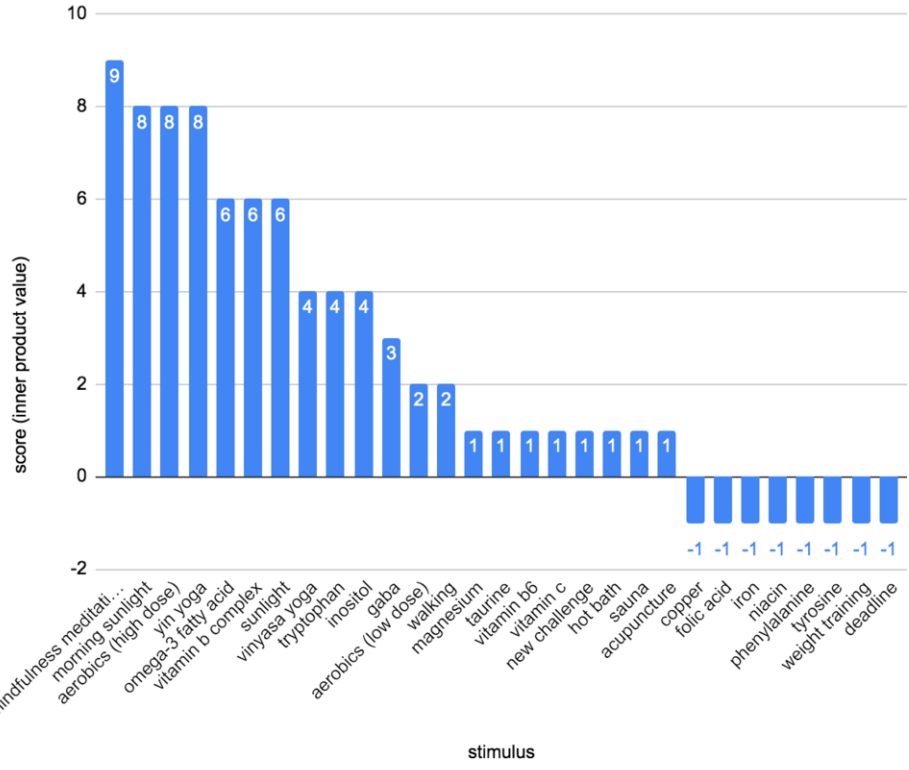

Figure 5. General Solutions for Calmness Ordered by Score (Inner Product Value)

Figure 6 shows the website score distribution of results after the second phase. Similar to the semantic search for "intrinsic motivation", the websites that include information on more stimuli tend to have a higher score. All information necessary for acquiring effective stimuli can be found.

This time, rank No.1 to 7 were all either general information or service information websites. Products that include multiple effective nutrients and single nutrients necessary for the production of multiple neurotransmitters had relatively high scores. This means that the priority of the information is assessed effectively. Discovering priority among multidisciplinary solutions is complex. However, it is automatically calculated and numerically expressed with our processing method.

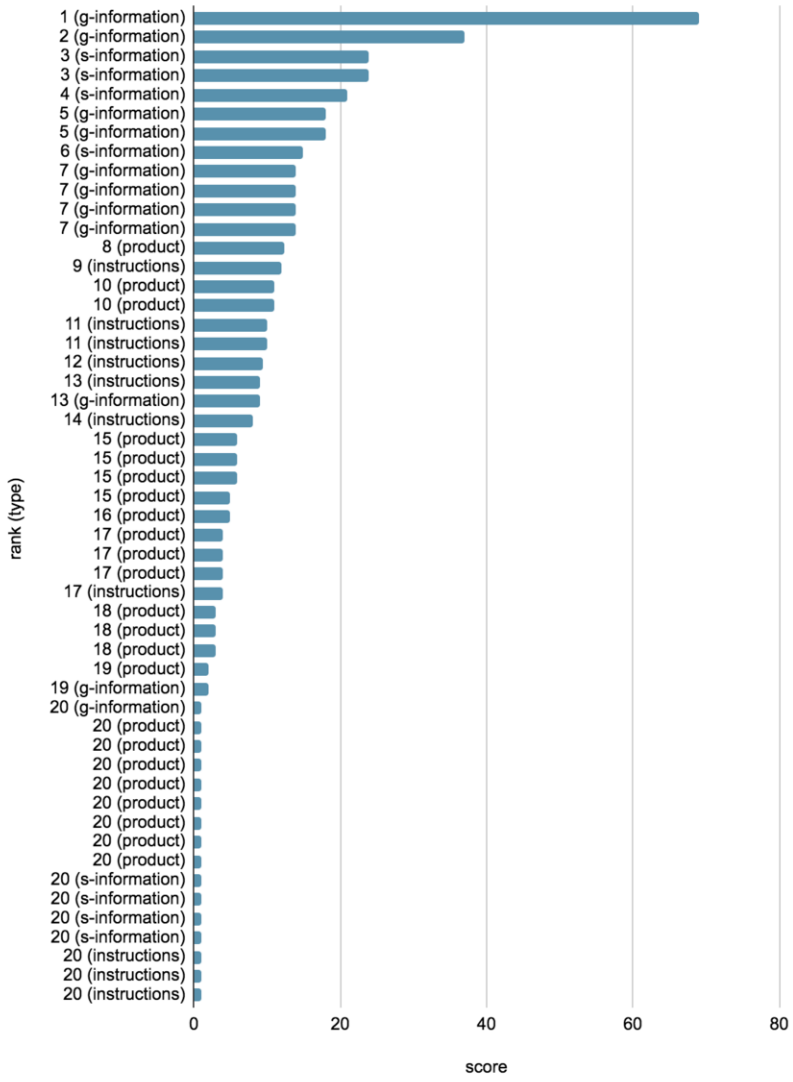

Figure 6. URL Score Distribution for Calmness (Ranking Ordered by Inner Product Value)

3.3 Evaluation of the Prototype Implementations

As Figure 7 shows high rates of recall and precision rates for each request, it can be said that 2-Phase Correlation Computing has a high performance in integrating multidisciplinary knowledge related to mental health.

The results of the first-phase correlation computing showed General Solutions that reflect specialists' decisions on achieving each mental state. The results derived from request vectors with minus values had relatively low recall and precision rates.

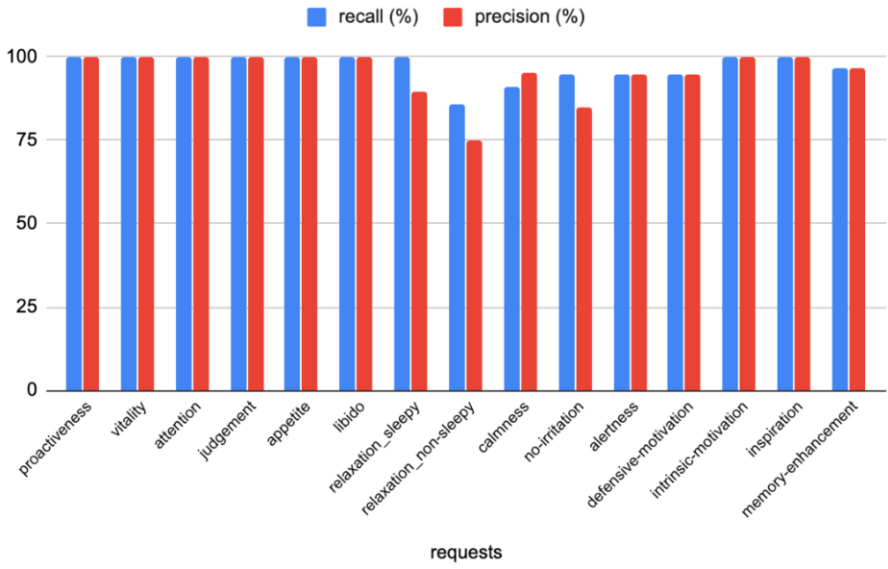

Figure 7. Recall & Precision Rate after 2-Phase Correlation Computing

The results of the second-phase correlation computing also showed scores of effective URLs that reflect specialists' decisions. URLs with score 1 have information or a product of a single stimulus, whereas higher scores were observed in general information, service information websites, products, and instructions that include multiple stimuli.

When filtering the results based on their types or costs, the differences in the score decreased. This indicates that specific types of information tend to show similar values.

4. Conclusion

In the prototype implementation, the notable features stated below were observed. They were realized with 2-Phase Correlation Computing. The main contribution of this research is the new information processing method for the integration of multidisciplinary knowledge on mental health. 2-Phase Correlation Computing can be a core function of a meta-level architecture for a mental health database. The current characteristics of the database are as stated below:

First, in this system, the user can choose the desired goal simply by the state name, and in the database, it is automatically converted into numbers.

Second, 2-Phase Correlation Computing allows finding multidisciplinary methods easily. This processing is dynamic and flexible. In this processing method, new parameters can easily be added, which means it has high scalability.

Third, the solutions are shown as a table. Currently, actuation is done within the database. Creating a web interface will allow many people to access this system.

"A Mental Health Creation Method with Neuroscience-inspired Search Functions" realizes a highly accurate and comprehensive information discovery for improving mental health. This is realized with its unique information processing, 2-Phase

Correlation Computing. This original method enables a comprehensive evaluation of various types of information on mental health. Utilizing the combinatorial vector, the user can discover effective solutions from multidisciplinary fields related to mental health in the first phase. In the second phase, concrete URLs containing information or products that include effective solutions are extracted. One of the advantages of this method is that both General Solutions and URLs can be extracted based on the user's preference. The information type can also be specified. This flexibility enables the user to find solutions that match his/her needs.

The novelty in this research is that it provides an information processing method to the field of mental health management. Sensing, processing, and actuation are three key elements for a system with an input and an output. The knowledge for improving mental health is usually patterns of the symptoms and treatments. On the other hand, our system offers interactive and dynamic processing for finding mental health solutions. By choosing a mental health goal as an input, customized information on effective solutions is shown as an output. The key achievement of this database creation method is processing. Through automatic curation, many types of people who are eager to increase their mental well-being or performance could benefit. The 2-Phase Correlation Computing showed a good performance in the universal evaluation of information related to mental health. Creating symbolic filter functions and an automatic pattern-making system for information will enable a more sophisticated information delivery.

In the future, processing could be improved to reflect expert knowledge on mental health more elaborately, including parameters other than neurotransmitters. For example, the endocrine system or brainwave balance can be reflected in creating a semantic space. With a new vector space creation that includes expert knowledge on health, it can also be applied to all health information. Enriching sensing and actuation functions will increase the usability of this research as well. Sensing can be improved to reflect the user's mental state more precisely, and actuation can be improved to offer information in more practical ways. Also, if vector space creation and website information retrieval from the Internet can be automated, the 2-Phase Correlation Computing can become an even more powerful platform for searching and analyzing health information.

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