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Testing inequality of lengths of three dimensions underlying the structure of individual variation in 6 sleep-wake abilities and 6 broad personality traits

Arcady A. Putilov[a], Dmitry S. Sveshnikov[b], Zarina V. Bakaeva[b], Elena B. Yakunina[b], Olga V. Mankaeva[b], Vladimir I. Torshin[b], Elena A. Trutneva[c], Michael M. Lapkin[c], Zhanna N. Lopatskaya[d], Roman O. Budkevich[e], Elena V. Budkevich[e], Dmitry E. Shumov[b,f], Anton I. Taranov[f], Olga N. Tkachenko[f], Eugenia O. Gandina[f], Alexander E. Manaenkov[f], Evgeniy A. Cheremushkin[f], Natalya V. Ligun[f], Alexandra N. Puchkova[f] and Vladimir B. Dorokhov[f]

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ABSTRACT

The dimensionality of structures proposed to explain the interrelations among several individual traits can be overestimated due to applying factor-analytic methodology for uncovering factorial dimensions of such structures. Although the factors are forced into orthogonality by means of rotation, significant inter-correlations are always found among questionnaire scales constructed for assessment of these factors. The assumption of inequal lengths of the axes of such structures provides the possibility to map 6 dimensions yielded by factor analysis on the surface of three-dimensional shape. Mathematically, this shape is a triaxial ellipsoid (i.e. an ellipsoid with three inequal axes) named "rugby cake" for simplicity. Here, this assumption of inequality of the axes of this shape was tested using (1) data on correlation coefficients among 6 scales of the questionnaires designed to assess 6 broad personality traits and 6 sleep-wake abilities that were collected from 3676 participants of three surveys, and (2) 100 matrices of correlation among 6 HEXACO's scales (Honesty-Humility-Emotionality-eXtraversion-Agreeableness-Conscientiousness-Openness to Experience) from the literature. Results supported the assumption of inequal lengths of three axes of "rugby cake" representation of individual variation in personality traits and sleep-wake abilities. This representation can be used for predicting factorial structure of yet-undeveloped questionnaires and missed questionnaire scales.

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Introduction

When several individual traits/abilities are recognized in a study of individual variation, it is necessary to reveal a structure (shape) explaining the interrelations between these traits/abilities. The most valuable are the parsimonious (e.g. in terms of geometry and dimensionality) shapes (Maraun 1997). The methodology for uncovering such shapes usually includes an analysis of patterns of correlations among the responses to questionnaire items. In a good deal of questionnaire studies, factor analysis is applied to analyze this pattern for reducing the dimensionality of the empirical structure without big loss of information.

For example, the results of numerous studies of the long lists of questionnaire items or personality descriptive terms suggested that factor analysis usually allows the recovering of 5 or 6 orthogonal factorial dimensions (McCrae and Costa 1987; Goldberg 1990; De Raad et al. 1998, 2014; Saucier 2003; Ashton et al. 2004). However, as it was noted by Block (1995), Maraun (1997) and some other, the factor-analytic methodology tends to overestimate dimensionality of the structure of individual variation.

Therefore, we previously showed that, if 5–6 dimensions were yielded by factor analysis of questionnaire items, the reduction of dimensionality to just three spatial dimensions can be allowed by proposing the lengths of axes of the analyzed structure of individual differences are inequal (Putilov 2016, 2018). This structural model is parsimonious in terms of geometry and dimensionality. It can be visualized in three-dimensional (3-D) space, and it was named "rugby cake" (i.e. one of well-known culinary molds), because, geometrically, this is a triaxial (scalene) ellipsoid (i.e. an ellipsoid with three dimensions of inequal length; Figure 1). Using the model postulating such 3-D representation of individual differences, new questionnaires were developed to assess 6 broad personality traits (Putilov 2018) and 6 sleep-wake abilities, respectively (Putilov 2016; Putilov et al. 2021).

The advantages of the 3-D rugby cake shapes are not limited by their parsimoniousness in terms of geometry and dimensionality. Even when the factor-analytic results of the previous studies were directly used to construct just a 3-D structural representation of personality lexicon, some of the areas of its surface were found to be densely populated with personality-relevant words, while the opposing areas contained long gaps, for instance, in the areas of combination of the opposite poles of the broad factors of Conscientiousness (III) and Agreeableness (II) (e.g. Hofstee et al. 1997; Di Blas and Forzi 1999). Moreover, 6 scales constructed for scoring 6 orthogonal factorial dimensions were found to correlate one with another (Goldberg 1990; Hofstee et al. 1997; Saucier and Ostendorf 1999; De Raad et al. 2014). In particular, the results of comparison of matrices of correlations among the HRXACO's scales suggested that these correlations are not negligible and replicable. The rugby cake shape provides an explanation for such relatively high/low abundance of words of the opposite poles of the factorial structures as well as for the replicable correlations among 6 scales constructed for scoring broad personality traits. Namely, the coordinates of factorial dimensions on the surface of the 3-D shape are not fully orthogonal due to the inequality of the spatial dimensions underlying the personality traits structure. Therefore, the personality-relevant words can be more evenly distributed on the surface of the rugby cake shape (Figure 1) with inequal lengths of its axes leading to their non-orthogonality (Putilov 2018).

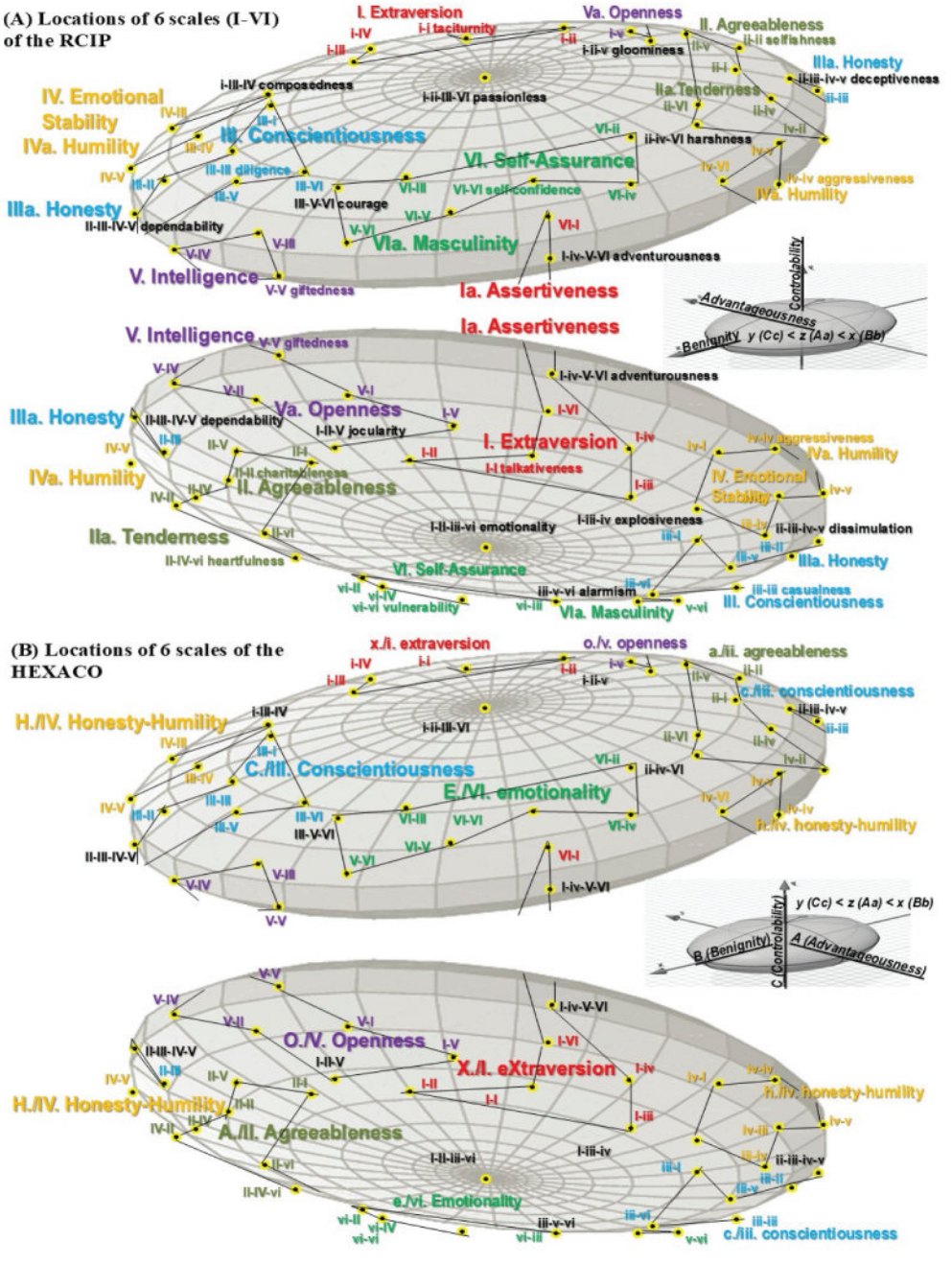


Figure 1. Mapping 6 scales for assessment of personality traits at the surface of 3-D shape. (A and B): The 3-D model of structure of individual variation was proposed to explain the relationships among 6 factorial scales designed to assess individual variation in personality on the examples of structural representation of two personality questionnaires, the RCIP and HEXACO, respectively. In geometrical terms, this 3-D shape is a scalene (triaxial) ellipsoid that might be illustrated for simplicity by the culinary mold known as "rugby cake". It has only three spatial (underlying) dimensions, *A*, *B*, and *C*. In such a three- rather than 6-dimensional structure of individual variation, 6 factorial dimensions yielded by factorial analyses of a questionnaire (e.g. either the RCIP or the SWPAQ) are interpreted as the

The question arises whether empirical data collected with such questionnaires support the assumption that three dimensions underlying the structural representations of individual differences are inequal in length. Here, we empirically examined the hypothesis of inequality of lengths of such three dimensions of the rugby cake shape on examples of questionnaires, two of which are designed to assess 6 broad personality traits and two of which are designed to assess 6 sleep-wake abilities.

Material and methods

To test the assumption of inequality of the axes of the rugby cake representation of individual differences, we used:

- data on correlation coefficients among 6 scales of the three questionnaires designed to assess 6 broad personality traits and 6 sleep-wake abilities that were obtained in three our studies, and,

– matrices of correlation among 6 HEXACO's scales collected from the personality literature.

Participants of questionnaire studies

University students and lecturers were invited to respond from their smartphones to the questions concerning personality and sleep-wake traits, habits and behavior. Two web sites were developed for collecting responses from 1641 and 1006 study volunteers (the 1st and 2nd sample, respectively) to three questionnaires. No special inclusion/exclusion criteria were applied. Each participant filled each questionnaire only once. The mean ages ± standard deviation of male and female students and lecturers were 19.08 ± 2.39 and 19.28 ± 1.82 years, and 42.07 ± 13.10 and 42.85 ± 12.47 years (n = 719 and 1615, and 72 and 241, respectively). Most recently, a new web site was developed and used to additionally collect responses from 1029 students-participants (the 3rd study) to one questionnaire. The mean ages ± standard deviation of male and female students were 20.17 ± 2.07 and 20.42 ± 3.36 years (n = 280 and 749, respectively).

For correlation analysis, the sample collected in each study was subdivided into subsamples with approximately 50 participants per subsample to obtain 20 such subsamples of the 2nd and 3rd studies and 30 subsamples of the 1st study.

Russian-language questionnaires with 6 scales administered in surveys

The list of questionnaires of the 1st and 2nd studies included three Russian-language questionnaires for assessment of individual variation in the domains of personality psychology and chronopsychology. Personality was assessed with adjective and noun

unique combinations of these three spatial (underlying) dimensions. The poles of 6 broad personality traits (I-VI) were mapped on the surface of rugby cake shape by assigning them to the combinations of the poles of underlying dimensions $\underline{A}$,$\underline{B}$, and $\underline{C}$. Filled and open circles denote the location of high and low poles of 6 scales, respectively (e.g. the poles of six factors or scales of the RCIP and HEXACO). Additionally, each of 6 scales of the RCIP was divided into subscales and their numeration (i.e. the combination of Roman numerals) reflects the correlation between subscales of neighboring scales.

versions of the 172-word Rugby Cake Inventory of Personality (RCIP) (Putilov 2018) in the 1st and 2nd study, respectively. Sleep-wake ability was assessed in these studies with two questionnaire tools, the 72-statement Sleep Wake Pattern Assessment Questionnaire (SWPAQ) (Putilov, 2007) and a reduced (60-item) version (Putilov et al. 2021) of the 168-statement Sleep-Wake Adaptability Test (SWAT; Putilov 2016).

Each of three questionnaires includes 6 scales that can be mapped at the surface of the rugby cake representation of individual variation in personality traits (RCIP; Figures 1a and 3a) and sleep-wake abilities (SWPAQ and SWAT; Figures 2 and 3b).

The 1st russian-language questionnaire: RCIP

The RCIP (Figure 1A) was constructed for testing some of the predictions of the 3-D rugby cake model of individual variation in personality traits (Putilov 2018). It consists of 172 personality-relevant adjectives or nouns (the samples of the 1st and 2nd study, respectively). Of them, 168 are grouped into scales representing six broad personality traits that are, in accord with tradition of the Big Five studies, named by Roman numerals "I-VI" (Figures 1a and 3a). The narrow traits known under their names in natural language were shown to be evenly distributed on the surface of the rugby cake shape. Consequently, each of 6 scales associated with 6 factorial dimensions (I–VI) represents a group of narrow traits. Some of narrow traits were included in a broader trait named "core broad trait" (I–VI) that was further enlarged by adding a smaller group of narrow traits named "adjacent traits" (Ia–VIa) because a narrow trait included in such a smaller group can be viewed as a mixture of neighbour core broad traits (Figure 1a).

Since 5 of these 6 scales resemble the Big Five factors, they were labeled by the traditional Roman numerals to denote Russian counterparts of factors I (Extraversion), II (Agreeableness), III (Conscientiousness), IV (Emotional Stability), and V (Intelligence or Intellect) of the Big Five. The sixth factor (VI) was previously interpreted as Self-Assurance (Putilov 2018) and Toughness (Shmelyov & Pokhil'ko, 1993) in the explicit and implicit studies of the Russian personality lexicon, respectively. The estimates of reliability (Cronbach's α) obtained in the 1st and 2nd studies were 0.821 and 0.817, 0.851 and 0.842, 0.840 and 0.834, 0.831 and 0.836, 0.796 and 0.769, and 0.780 and 0.785 for the scales representing the broad personality traits I, II, II, IV, V, and VI, respectively (Figures 1a, 2a, and S1A).

The 2nd Russian-language questionnaire: SWAT

The 168-statement SWAT was developed for testing several predictions of the 3-D rugby cake model of individual variation in sleep-wake adaptability (Figures 1b, 2b and S2). Its full version includes six 28-item scales (Putilov 2016). Each of the scales was shortened to 10 items in the reduced version by excluding items with relatively low item-scale correlations (Putilov et al. 2021). In the 1st and 2nd studies, Cronbach's αs were 0.716 and 0.706, 0.760 and 0.677, 0.680 and 0.678, 0.706 and 0.697, 0.759 and 0.763, 0.729 and 0.673 for the SWAT's scales for assessment of Morning Sleepability, Nighttime Wakeability, Daytime Wakeability, After 24 h Wakeability, Daytime Sleepability, and Nighttime Sleepability, respectively (Figures 1b, 2b, and S3).

To provide further support for the replicability of results of the first and second studies, the SWAT was additionally administered in the 3rd study (Figure 3).

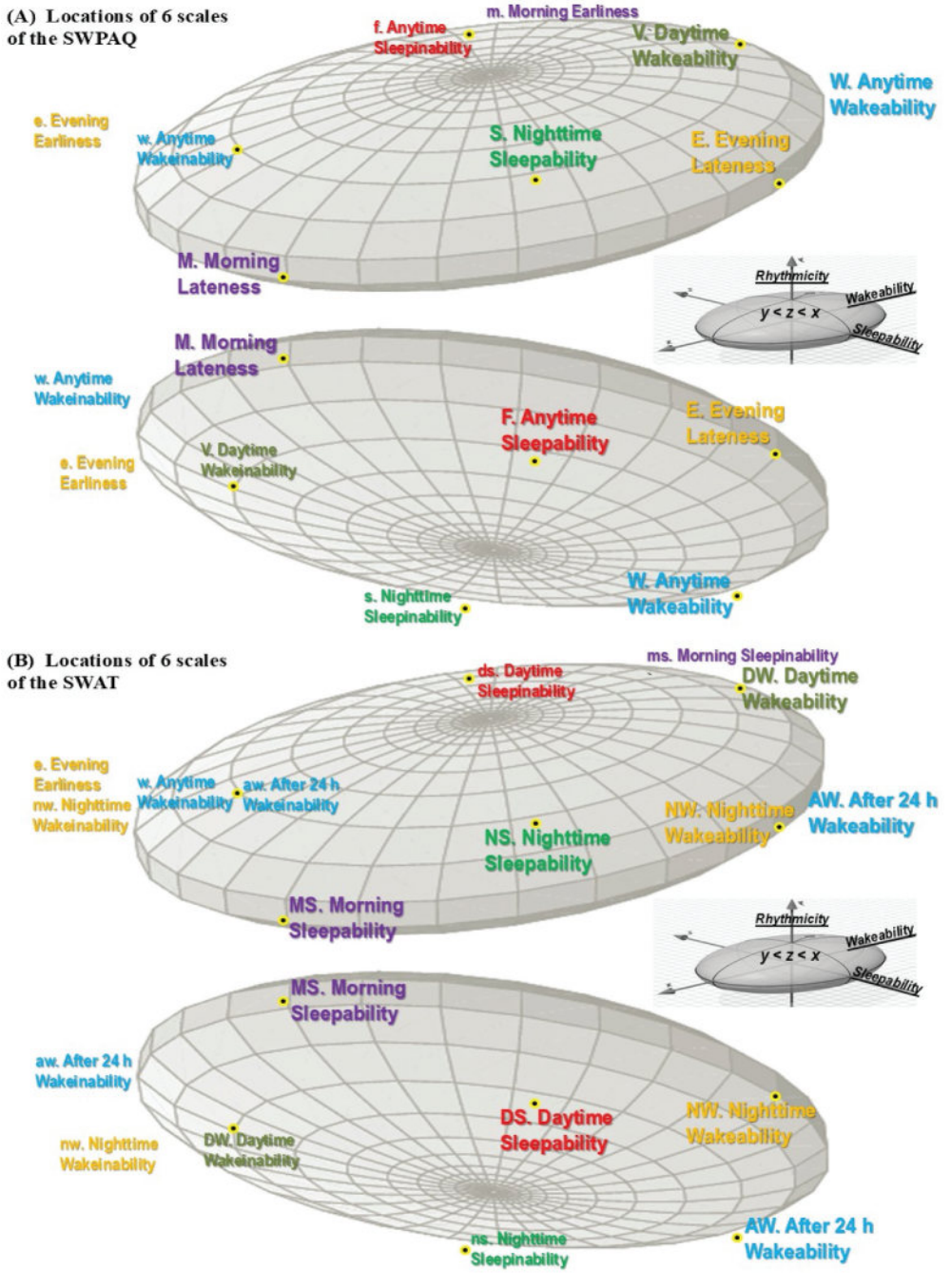


Figure 2. Mapping 6 scales for assessment of sleep-wake adaptability at the surface of 3-D shape. The same 3-D model of structure of individual variation was proposed to explain the relationships among 6 factorial scales for assessing individual differences in personality (Figure 1) and sleep-wake ability (this figure). (A and B): The model is exemplified by the 3-D structural representation of two questionnaires for assessing adaptive abilities of sleep-wake behavior and habits, the SWPAQ and SWAT, respectively. The poles of 6 sleep- and wakeabilities were mapped on the surface of rugby cake shape by assigning them to the combinations of the poles of underlying dimensions*A*,*B*, and*C*. See other notes in the legend to Figure 1.

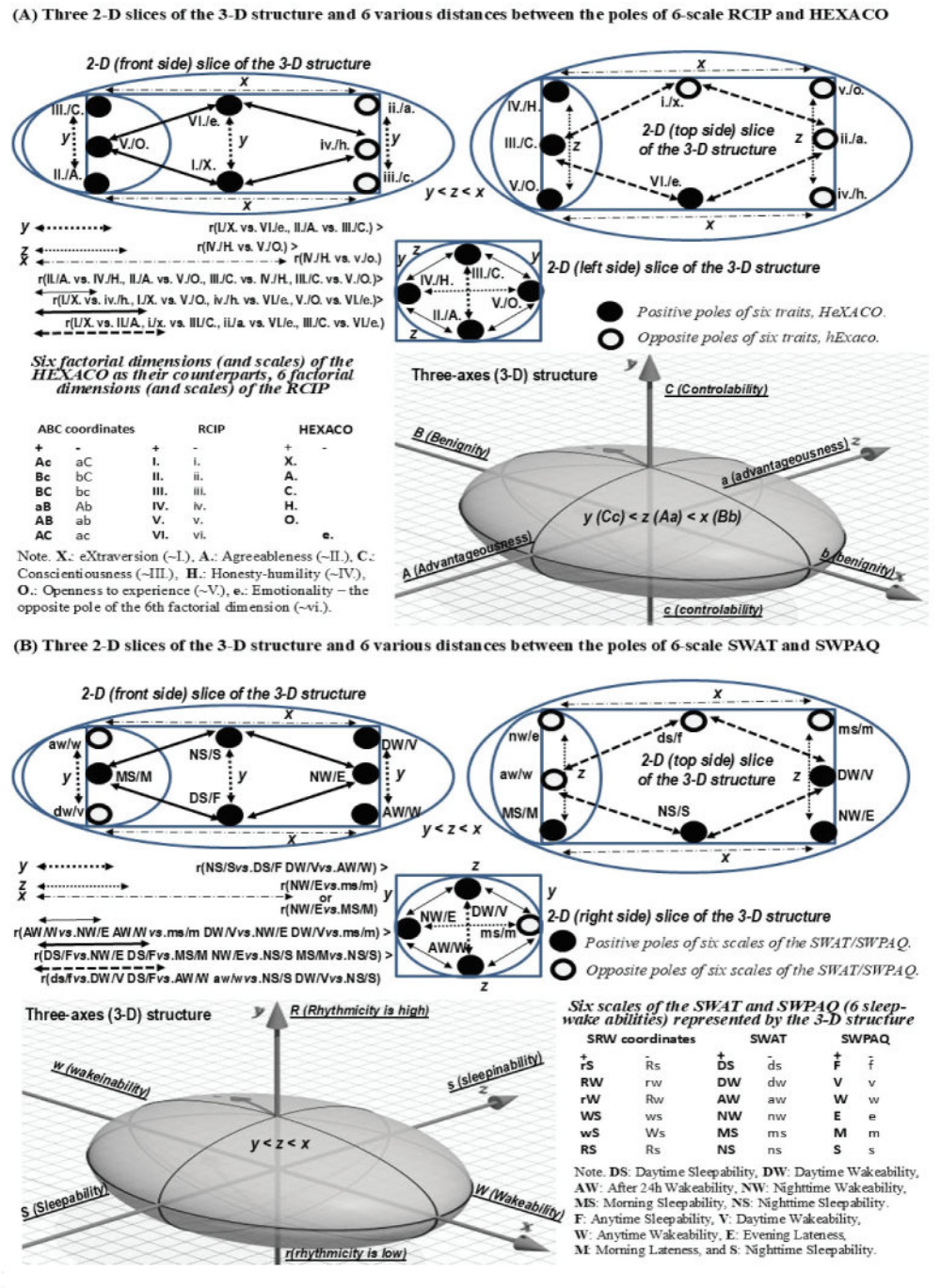


Figure 3. Measurement of spatial distances between 6 scales of 4 questionnaires. Three 2-D slices of the 3-D structure illustrate the spatial distances between 6 scales that can be grouped in shorter, intermediate and longer distances. It is expected that correlation coefficient is proportional to the distance between correlated scales, i.e. it is stronger for shorter than longer distance. Consequently, 15 coefficients among 6 scales can be grouped in coefficients for shorter, intermediate and longer distances. Two groups are characterized by the shortest distances (along Y-axis), the distances of

The 3rd Russian-language questionnaire: SWPAQ

Initially, the 3-D model was proposed for explaining the pattern of intercorrelations among scales of the earliest of questionnaires with 5 or 6 scales for assessment of sleep-wake abilities (SWPAQ; Putilov, 2007). Cronbach's α is calculated for the samples of the 1st and 2nd studies were 0.716 and 0.706, 0.760 and 0.677, 0.680 and 0.678, 0.729 and 0.673, 0.759 and 0.763, and 0.706 and 0.697 for Morning Lateness, Evening Lateness, Daytime Wakeability, Anytime Wakeability, Anytime Sleepability, and Nighttime Sleepability, respectively. They are the counterparts of the SWAT's scales Morning Sleepability, Nighttime Wakeability, Daytime Wakeability, After 24 h Wakeability, Daytime Sleepability, and Nighttime Sleepability, respectively (Figures 1b, 2b, and S3).

An English-language questionnaire: HEXACO

The list of three questionnaires of our three surveys does not contain the most widely used English-language questionnaires. Therefore, the collected samples cannot represent the populations of other countries. However, at least in the domain of personality psychology, further support of our results and evidence for the possibility of their generalization can be provided by analysis of one of English language personality questionnaires, the HEXACO (Ashton et al. 2004), that also includes 6 scales developed from 6 factorial dimensions. Many researchers already administered this questionnaire to people from different countries around the globe. Since 15 intercorrelations among 6 scales of the HEXACO (Honesty-Humility, Emotionality, eXtraversion, Agreeableness, Conscientiousness, and Openness to Experience) can be found in numerous publications applying this questionnaire, it was not necessary to collect a new HEXACO dataset for the present analysis aimed on confirmation of results on the RCIP.

A literature search for matrices of correlations among 6 scales of the HEXACO

Publications reporting one or more matrices of correlations among 6 HEXACO scales were identified by searching in Scopus bibliographic database from inception to 10 April 2023. Syntax for conducting the search was the following:

TITLE-ABS-KEY (HEXACO)

In total, 880 articles (ranged by Scopus in alphabetic order of journal titles) were identified. The assessment for eligibility was performed by applying the following eligibility criteria: (1) an article contains a table(s) with one (more than one) matrices of intercorrelations among the HEXACO's scales, and (2) however, the search is stopped after the collection of the last, 100th matrix. By applying these criteria, we searched the content of less than 1/3 of these 880 identified articles to collect the target amount (100) of

two more groups are intermediate (along Z-axis), and the distances of two last groups are the longest (along X-axis). (A) and (B): Illustration of distances between personality scales (RCIP and HEXACO) and sleep-wake adaptability scales (SWAT and SWPAQ), respectively. See also Figures S1 and S2 for the results of comparison of correlation coefficients among scales divided by shorter, intermediate and longer distances along Y-, Z- and X-axis, respectively.

Table 1. Comparison of correlation coefficients among scales located on three distances.

Questionnaire		HEXACO	RCIP	SWPAQ	SWAT
Total # of matrices or 50-participant groups		100	50	50	70
Effect of repeated measure "Distance" (Shorter, Intermediate and Longer)					
Degree of freedom		2/198	2/98	2/98	2/138
F-ratio		426.6***	458.1***	192.6***	357.3***
Level of significance		<0.001	<0.001	<0.001	<0.001
Pairwise comparisons of coefficients among scales located on three distances					
Shorter vs.	mean difference	0.089	0.239	0.225	0.327
intermediate distance	level of significance	<0.001	<0.001	<0.001	<0.001
Shorter vs	mean difference	0.214	0.446	0.437	0.362
longer distance	level of significance	<0.001	<0.001	<0.001	<0.001
Intermediate vs.	mean difference	0.125	0.207	0.212	0.041
longer distance	level of significance	<0.001	<0.001	<0.001	0.095

Note. For each of 4 questionnaires, repeated measures ANOVA was applied to three mean correlation coefficients among scales. These three coefficients were calculated by averaging over 6 shorter distances, 5 intermediate distances, and 5 longer distances (see these distances in Figure 3). The coefficients were either taken from two sets of 50 matrices each (HEXACO) or calculated by analysis of 50 or 70 groups including 50 study participants (RCIP, SWAT and SWPAQ). The following three null hypotheses were tested in *post hoc* pairwise comparisons: (1) the averaged coefficients among the scales located on intermediate and shorter distances are not different, (2) the averaged coefficients among the scales located on longer and shorter distances are not different, and (3) the averaged coefficients among the scales located on longer and intermediate distances are not different. If all three null hypotheses are supported, all three dimensions of the structural representation of individual variation are equal in length. See also Figure 4 illustrating the coefficients obtained for two separate sets of 50 matrices (HEXACO), two separate studies (RCIP and SWPAQ) and three separate studies (SWAT).

correlation matrices. The publications containing one or more eligible matrices are listed in Supplementary Materials.

Statistical analysis

The $SPSS_{23.0}$ statistical software package (IBM, Armonk, NY, U.S.A.) was used to calculate correlations between scores on 6 scales of each questionnaire and to compare strength of these correlations. For each questionnaire, Spearman correlation coefficients (ρ) among 6 scales were calculated for each of app. 50-participant subdivisions of the study samples. The geometry of this ellipsoid shape predicts that, the strength of each of 15 coefficients is proportional to the spatial distance between this pair of scales mapped on the surface of the triaxial ellipsoid (Figure 3, S1 and S2). Correlation is expected to be stronger among pairs of scales on a shorter distance, less strong among pairs of scales on an intermediate distance, and even weaker among pairs of scales on a longer distance. For each questionnaire, repeated measures ANOVA was run to compare the coefficients among scales located on such shorter, intermediate and longer distances (Table 1). F-ratio was calculated for the repeated measure (three – shorter, intermediate and longer – distances). Degrees of freedom were corrected using Greenhouse–Geisser correction controlling for type 1 errors associated with the violation of the sphericity assumption, but the original degrees of freedom are reported in Table 1. In *post hoc* pairwise comparisons of correlation coefficients obtained for shorter, intermediate and longer distances, the null hypothesis of equality of these correlation coefficients was tested. If this hypothesis is supported, three dimensions of the structural representation of individual variation are equal in length.

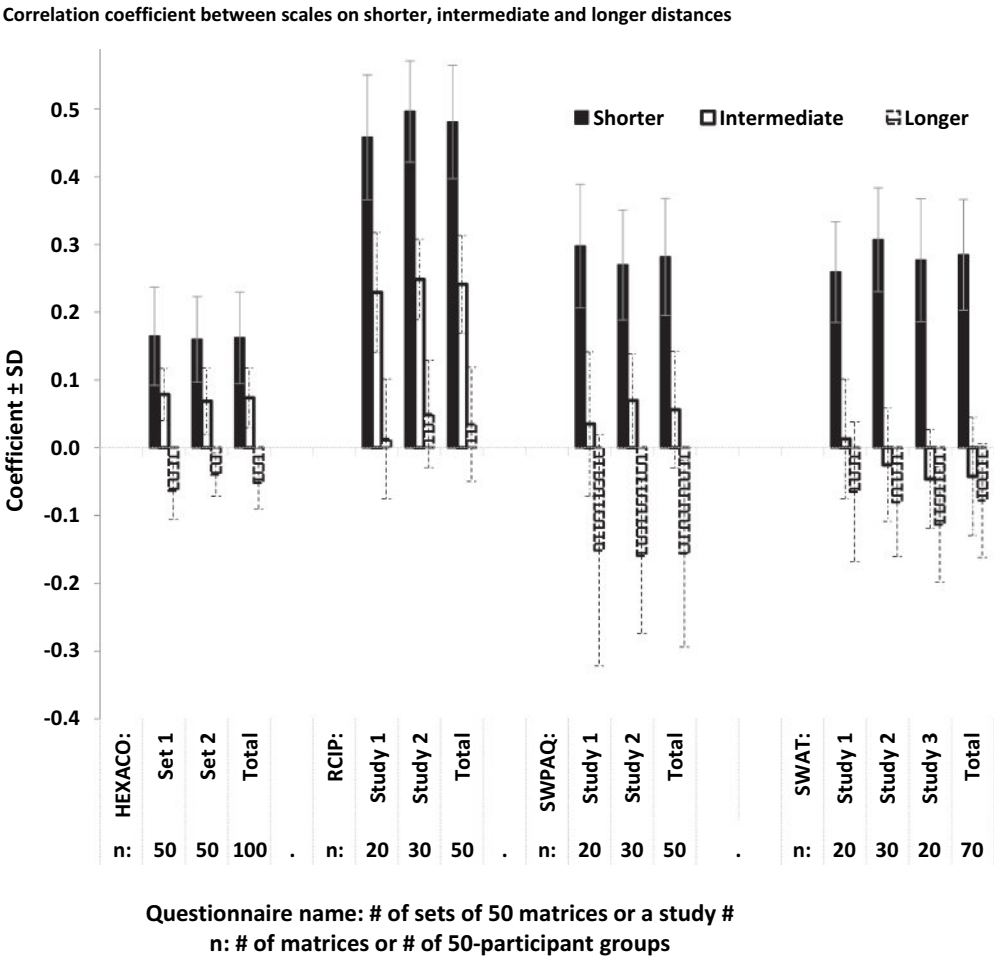


Figure 4. Correlation coefficients among scales divided by shorter, intermediate and longer distances. For each of 4 questionnaires, correlation coefficients were calculated by averaging over coefficients for 6 shorter distances, 5 intermediate distances, and 5 longer distances (see these distances in Figure 3, S1 and S2). The coefficients are illustrated for two separate sets of 50 matrices and $2 \times 50 = 100$ matrices in total (HEXACO), for two separate studies of groups consisting of 50 study participants and $20 + 30 = 50$ groups in total (RCIP and SWPAQ), and for three separate studies of groups including 50 study participants and $20 + 30 + 20 = 70$ groups in total (SWAT). See Table 1 for the results of statistical analysis of the coefficients on three distances.

Additionally, to support the results on repeated measure ANOVAs, paired t-test was applied to the differences between mean correlation coefficients (Table 2). The following three null hypotheses were t-tested with Bonferroni correction for number of comparisons (three): (1) the difference between averaged coefficients among the scales located on shorter and intermediate distances is equal to zero, (2) the difference between averaged coefficients among the scales located on shorter and longer distances is equal to zero, and (3) the difference between averaged coefficient among the scales located on intermediate and longer distances is equal to zero. If all three null hypotheses are

Table 2. Comparison of difference in correlation coefficients for three distances with zero.

Questionnaire		HEXACO	RCIP	SWPAQ	SWAT
Total # of matrices or 50-participant groups		100	50	50	70
Shorter -	mean difference	0.089	0.239	0.225	0.327
intermediate	−95% confidence interval	0.073	0.213	0.194	0.300
distance	+95% confidence interval	0.105	0.266	0.256	0.353
	t	11.123	17.879	14.631	24.874
	level of significance	<0.001	<0.001	<0.001	<0.001
Shorter -	mean difference	0.215	0.446	0.437	0.362
longer	−95% confidence interval	0.199	0.412	0.388	0.332
distance	+95% confidence interval	0.230	0.480	0.487	0.392
	t	27.283	26.623	17.898	24.096
	level of significance	<0.001	<0.001	<0.001	<0.001
Intermediate -	mean difference	0.126	0.207	0.212	0.036
longer	−95% confidence interval	0.114	0.179	0.161	0.003
distance	+95% confidence interval	0.138	0.235	0.264	0.069
	t	20.866	14.886	8.276	2.152
	level of significance	<0.001	<0.001	<0.001	0.095

Note. For each of 4 questionnaires, paired t-tests were applied to compare the differences between mean correlation coefficients with zero difference. These three coefficients were calculated by averaging over 6 shorter distances, 5 intermediate distances, and 5 longer distances (see these distances in Figure 3). Each coefficient was either taken from two sets of 50 matrices (HEXACO) or calculated by analysis of 50 (RCIP, SWPAQ) and 70 groups including 50 study participants (SWAT). The following three null hypotheses were tested by applying t-test with Bonferroni correction for the number of comparisons (three): (1) the difference between averaged coefficients among the scales located on shorter and intermediate distances is equal to zero, (2) the difference between averaged coefficients among the scales located on shorter and longer distances is equal to zero, and (3) the difference between averaged coefficient among the scales located on intermediate and longer distances is equal to zero. If all three null hypotheses are supported, all three dimensions of the structural representation of individual variation are equal in length. See also Figure 5 for mean and standard deviations of the differences.

supported, all three dimensions of the structural representation of individual variation are equal in length (Table 2).

The same statistical analyses were applied to the correlation coefficients reported for 6 HEXACO scales. Instead of calculation of 50–70 matrices for app. 50-participant groups for further analysis of the structures of the RCIP, SWAT and SWPAQ, two sets of 50 published matrices were subjected to the repeated measure ANOVAs and paired t-testing of the HEXACO structure (Figure 5 and Tables 1 and 2).

Results

The theoretic framework of the model

The theoretical framework of the rugby cake model was presented in details in previous publications (Putilov 2016, 2018). Therefore, its brief description is included in Supplementary Materials.

Testing inequality of lengths of three spatial dimensions

Figures 1 and 2 illustrate the locations of 6 broad personality traits and 6 sleep-wake abilities, respectively, at the surface of triaxial ellipsoid, i.e. an ellipsoid with three inequal axes, or, for simplicity, rugby cake. Due to such inequality of the lengths of axes of such

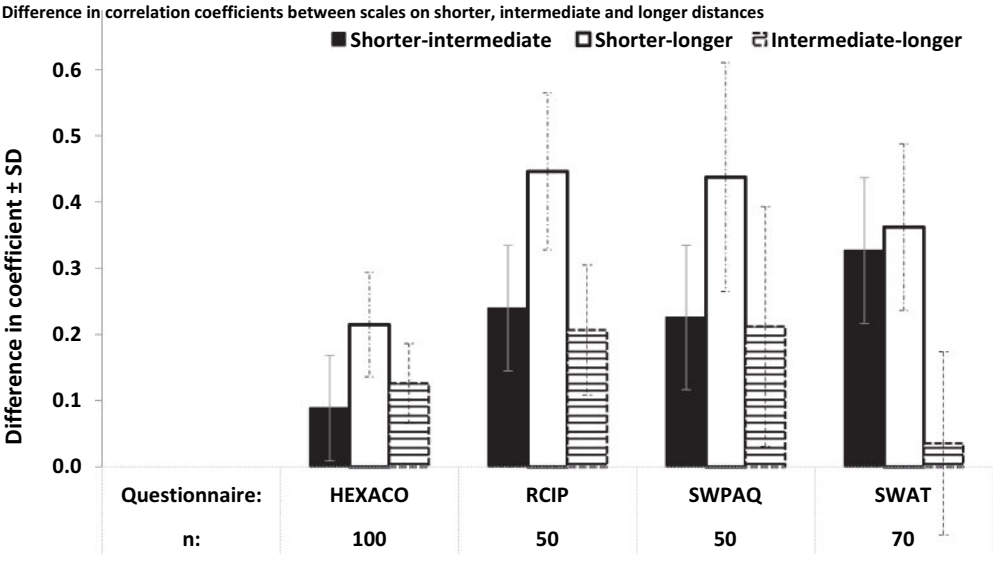


Figure 5. Differences between correlation coefficients among scales divided by shorter, intermediate and longer distances. For each of 4 questionnaires, three differences between mean correlation coefficients (see Figure 3) were calculated. See other notes in the legend to Figure 2, and see Table 2for the results of statistical analysis of these differences.

a 3-D shape, the inequality of correlation coefficients among scores on 6 scales for assessment of these 6 traits/abilities can be expected. Namely, the shorter distance, the stronger coefficient.

Although there are as many as 15 spatial distances between 6 scales (or 15 correlations among 6 scales) mapped at the surface of triaxial ellipsoid (6!/4!2! = 1·2·3·4·5·6/1·2·3·4·1·2 = 15), the geometry of this model suggests that these 15 spatial distances (or 15 correlations) can be grouped in 6 spatial distances (or 6 averaged correlations) shown in Figure 2, S1 and S2. Two groups are characterized by the shortest distances, the distances of two more groups are intermediate, and the distances of two last groups are the longest (Figure 2, S1 and S2). Therefore, the number of groups can be further reduced to three groups o shorter, intermediate, and longer groups. Consequently, the inequality of spatial distances can be revealed by comparison of coefficients of correlation among 6 scales obtained for these three distances (Figures S1 and S2). Namely, the coefficients of correlation calculated for the group of intermediate distances are expected to be weaker than the coefficients of correlation calculated for the group of shorter distances. In contrast, these coefficients of correlation are expected to be stronger than the coefficients of correlation calculated for the group of longer distances.

For example, of these 6 groups of inequal distances, there are three groups each of which includes 4 equal distances (Figure 2). Since a questionnaire scale cannot ideally represent a trait/ability, one of calculated coefficients of correlation among two scales on equal distance might be stronger/weaker than the coefficient predicted by the model. However, in this case, the coefficient among two scales located on the opposite side of the shape on equal distance is expected to deviate from the predicted correlation in the opposite direction, i.e. this another

coefficient of correlation is expected to be weaker/stronger than the expected coefficient. There are 4 such possible deviations of the calculated coefficients of correlation from the expected coefficients. It is expected that any such deviation can be averaged out by the calculating mean coefficient of correlation for 4 spatial distances of the group of equal distances. Consequently, if three axes of the rugby cake shape are really inequal, the mean coefficient of correlation calculated for a group of intermediate distances is expected to be weaker than that calculated for a group of shorter distances, and, in turn, the mean coefficient of correlation calculated for a group of longer distances is expected to be weaker than that calculated for a group of intermediate distances (Figure 3, S1 and S2).

Such expectations can be confirmed in a questionnaire study thus providing empirical evidence for the inequality of three dimensions underlying the structural representations of personality traits or sleep-wake abilities. Coefficients of correlation were obtained for each of 5 intermediate distances to compare with coefficients obtained for 6 shorter distances and 5 longer distances (Figures S1 and S2). Figures 4 and 5 illustrate the results of such comparison, and Tables 1 and 2 include statistical results of this comparison.

Inequality of lengths of three dimensions the HEXACO, RCIP, SWPAQ and SWAT

In order to demonstrate the replicability of interrelationships among 6 scales of the HEXACO, two halves – the 1st and 2nd – of 100 matrices were separately analyzed and the results of such separate analyses are illustrated in Figures 4 and S1. As predicted by the structural model of personality traits, the obtained results were almost identical for two sets of 50 correlation matrices (Figure 4 and S1B). As indicated by the results of statistical analyses reported in Tables 1 and 2 and illustrated in Figures 4 and 5, the correlation coefficients became significantly weaker in strength for intermediate distances compared to shorter distances and, in turn, for longer distances compared to any of these two distances ($p < 0.001$ for any of comparisons).

The results of statistical analyses of the RCIP's and SWPAQ's correlations reported in Tables 1 and 2 and illustrated in Figures 4 and 5 also suggested that the correlation coefficients became significantly weaker in strength for intermediate distances compared to shorter distances and, in turn, for longer distances compared to any of these two distances ($p < 0.001$ for any of comparisons). However, the results of statistical analyses of the SWAT's correlations suggested that the difference between intermediate and longer distances did not reach a statistically significant level after correction for the number of comparison (Tables 1 and 2).

Overall, the statistical tests confirmed the prediction of inequality of lengths of the axes of the structures of individual variation in the domains of personality psychology and chronopsychology.

Discussion

If the dimensions underlying a structure of individual differences are inequal in length, this provides the possibility to reduce the dimensionality of structural model of individual variation in the domains of personality psychology and chronopsychology (Putilov 2016, 2018). The proposed rugby cake model postulates that as many as 6

factorial dimensions can be mapped on the surface of 3-D shape. We also previously used such structural model of individual variation for the development of new questionnaire tools for assessing individual differences in personality traits (Putilov 2018) and sleep-wake abilities (Putilov 2016; Putilov et al. 2021). Recently, data collected with such questionnaires were used to test the model's prediction that the three spatial dimensions underlying the structure of individual differences are, indeed, inequal in length. To provide the support for the results obtained with these questionnaires, this prediction was additionally tested using the literature data on correlations among the HEXACO scales. The results confirmed the model's prediction that the axes of the structures of individual differences are inequal in length. Thus, they provided further evidence for a plausibility of the 3-D rugby cake shapes as the structural representations of individual variation in the domains of personality psychology and chronopsychology.

The 3-D representation of individual differences can be used for predicting factorial structure of yet-undeveloped questionnaires and missed questionnaire scales (Putilov 2026). It predicts the following features of such questionnaires. (1) Factor analysis is expected to yield 6 factorial dimensions. (2) Scores on 6 factors are expected to show moderate or strong correlations with scores on their counterparts in the already developed 6-scale questionnaires. (3) Like the scales of already developed questionnaires, 6 new scales are expected to be mapped on the surface of the rugby cake shape, i.e. triaxial ellipsoid. (4) Their locations are expected to be confirmed by significant differences in three mean correlation coefficients between scales divided by shorter, intermediate and longer distances.

It is worth noting that, since this is the first study aimed on providing evidence for inequality of lengths of three dimensions underlying the 3-D structural representations of individual differences, this inequality requires further support in future studies. In our studies, the most widely used English language questionnaires were not administered, but, at least in the domain of personality psychology, the support for the study results and evidence for the possibility of their generalization was provided by the results on the HEXACO. Moreover, the statistical approach suggested in the present study might not be optimal and sufficient. Therefore, it might require reconsideration in further research.

Conclusions

The rugby cake model predicts that the three spatial dimensions underlying the structural representation of individual differences are inequal in length. Here, we tested the postulated inequality in questionnaire studies. The results of testing confirmed that the three spatial dimensions of the 3-D structure of individual differences seem to be inequal in lengths. These results provided further evidence for a plausibility of the rugby cake shape as the structural representation of individual variation in the domains of personality psychology and chronopsychology. However, since this is the first study aimed on providing evidence for inequality of lengths of three dimensions underlying the 3-D structural representations of individual differences, further support in further studies using independent datasets is required. The 3-D representation can be recommended for applying in future research to predict factorial structure of yet-undeveloped questionnaires and missed questionnaire scales.

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Data availability statement

Dataset of the survey is available from the first author on reasonable request.

Informed consent statement

The study participants were informed in detail about the survey procedure, and informed consent was obtained from each participant in the form of the response "Agree" to the following statement: "I give informed consent to anonymously and voluntarily participate in this online survey of sleep-wake behavior and habits".

Institutional review board statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Institute of Higher Nervous Activity and Neurophysiology (Approval#12402–02-7112 from 3 June 2019).

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