Three distinct patterns of mental health response following accidents in mountain sports – a follow-up study of individuals treated at a tertiary trauma center

Manuscript

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# Abstract

**Background:** Mountain sports are inherently linked to physical injury risk. We aimed to characterize mental health following mountain sport accidents requiring professional medical management.

**Methods:** Adult victims of mountain sport accidents treated at the Innsbruck University Hospital (Austria) between 2008 and 2020 (n = 307) participated in a cross-sectional survey study at median 44 months after the trauma center admission. Symptoms of anxiety, depression, somatization and panic disorder (PHQ), resilience (RS-13), sense of coherence (SOC-9L), quality of life (EUROHIS-QOL), post-traumatic growth (PTGI) and post-traumatic stress disorder (PTSD, PCL-5), sociodemographic and clinical information were obtained from an on-line survey and electronic health records. Mental health patterns were investigated by semi-supervised medoid clustering and modeled by machine learning.

**Results:** At least one diagnostic criterion of PTSD was met by 19% of participants. Three comparably sized subsets of patients were identified: (1) neutral, (2) post-traumatic growth and (3) post-traumatic stress cluster. The post-traumatic stress cluster was characterized by frequent mental disorder symptoms, and low resilience, sense of coherence and quality of life as well as by low age, the highest frequency of pre-existing mental disorders and common physical health consequences of the accident. Reliability of machine learning-based prediction of the cluster assignment based on 40 variables available during acute treatment was limited.

**Conclusion:** A subset of mountain sport accident victims shows symptoms of mental health disorders including PTSD. Since early identification of these vulnerable patients remains challenging, low-threshold psychological support is key for a successful interdisciplinary management of mountain sport accidents.

# Keywords

mountain sport accident, mental health, post-traumatic stress disorder, post-traumatic growth, machine learning

# Introduction

Physical activity in mountains, such as hiking, climbing, alpine skiing or ski touring, gain popularity, a trend that has been accelerated by the COVID-19 pandemic (1). Outdoor physical activity in general and mountain sport in particular exerts beneficial effects on mental health (2–4). However, mountain sports are also associated with the risk of injury (5,6), which could foster development of mental disorders including post-traumatic stress disorder (PTSD).

PTSD symptoms include hyperarousal, panic, somatic symptoms, sleep disorders and unwilling recalls of the trauma (flashbacks) (7–9), which can occur following self-experiencing or witnessing of a traumatic event such as actual or threatened death, injury, physical or sexual violence. PTSD may co-occur with symptoms of depression and anxiety and substance abuse disorders (10,11). Although most individuals have experienced at least one traumatic event during the lifetime (12,13), the prevalence of PTSD in the general European population has been estimated for 0.38 to 6.67% (14,15). Yet, up to 26% of acute physical trauma patients have been reported to develop PTSD (16).

So far it has proven difficult to identify early predictors of subsequent PTSD development in physical trauma patients. While some recent studies on specific populations have identified risk factors such as pre-existing psychological distress (17) or symptoms of mental disorders (18), others have focused on the arousal and stress reaction during acute trauma and peri-traumatic period as candidate predictors (19). These results require validation and further generalization before they can be implemented into routine care (20,21). Many trauma patients at risk of PTSD undergo intensive acute medical management at emergency departments, which poses a challenge for implementation of early diagnostic and psychological preventive measures (22). Furthermore, efficacy of such acute psychological interventions at preventing PTSD in trauma patients is uncertain, probably due to large heterogeneity of study cohorts (23).

Post-traumatic growth describes a salutary adjustment psychological reaction to a traumatic experience with strengthened perceptions of self, others, and meaning of the event (24). Resilience, i.e. the ability to master adversities has been proposed to bridge traumatic events and post-traumatic growth. It was also suggested to explain why most people do not develop PTSD despite the high prevalence of traumatic events in the general population (25,26). Overall, mountain sport was associated with high resilience values (2).

Reports on mental health following accidents during mountain sports are scarce. The available data concern mountain guides, rescuers or avalanche accident survivors (27–31). Considering the large number of mountain accident victims, and heterogeneity of accident and injuries, accurate characteristic of mental health of the affected patients is urgently needed. In particular, tools allowing for identification of patients at risk of later mental health problems during acute medical management of the mountain accident would facilitate the early targeted psychological support and help to preserve the positive mental health effects of physical activity.

Herein, we analyzed a broad palette of mental health readouts such as anxiety, depression, resilience, sense of coherence, quality of life, post-traumatic growth and signs of PTSD in a collective of 307 patients treated for injuries during mountain sport accidents at the Medical University of Innsbruck, Austria by means of semi-supervised clustering.  
Additionally, we searched for early sociodemographic and clinical predictors of mental health impairment following a mountain accident with a machine learning approach.

# Methods

## Ethics

The study was conducted in accordance with the Declaration of Helsinki and European data policies. All participants gave electronically signed written informed consent to participate. Participants’ data were processed in anonymized form. The study protocol was approved by the ethics committee of the Medical University of Innsbruck (approval number: 1472/2020).

## Participants

Patients treated for a mountain sport accident at the Department for Orthopedics and Traumatology at the Medical University of Innsbruck between 1st January 2018 and 31st December 2020 (i.e. at least 6 months prior to the start of the study) were screened for participation. Patients fulfilling the inclusion criteria: age 18 years, residence in a German-speaking country and proficiency in German (n = 4559) were invited to participate in the online study survey via conventional mail. Out of the invited subjects, 387 completed the survey and 307 individuals with the complete psychometry data were analyzed (**Figure 1**, **Supplementary Tables S1** - **S2**).

## Procedures

Details on study procedures and variables are provided in **Supplementary Methods** and **Supplementary Table S1**.

Sociodemographic (e.g. age, sex, education, profession, income, prior sport accidents and traumatic events), accident- and recovery-related (e.g. rescue, psychological support, persistent physical health consequences) and psychometric variables were recorded with a cross-sectional on-line survey.

The psychometric battery consisted of German versions of assessment tools for symptoms of anxiety (GAD-7: 7-item general anxiety disorder scale) (32), depression (PHQ: patient health questionnaire, PHQ-9, depression module) (33,34), panic (PHQ-panic module) (33,34), persistent somatic symptoms (PHQ-15, somatization module) (35), resilience (RS13: 13-item resilience scale) (36), lack of sense of coherence (SOC-9L: Leipzig 9-item sense of coherence questionnaire) (37), quality of life (EUROHIS-QOL 8: 8-item EUROHIS project quality of life scale) (38), post-traumatic growth (PTGI: post-traumatic growth inventory) (24) and post-traumatic stress disorder (PCL-5 DSM-5: PTSD checklist for DSM-5) (39). The tools displayed good-to-excellent consistency (40) (McDonald’s > 0.8, **Supplementary Table S2** and **S3**).

Clinically significant symptoms of anxiety (GAD-7 10), depression (PHQ-9 11) (41), persistent somatic symptoms (PHQ-15 11) (35) and resilience classes (low: RS-13 0 - 65, moderate: 66 - 72, high: 73)(36) were defined with published cutoffs.

Separate scores were calculated for domains B, C, D and E of the PCL-5 tool along with the total score being the sum of all items. Each PCL-5 item was scored as 0: not at all, 1: a little bit, 2: moderate, 3: quite a bit and 4: extremely. Participants positive for the B domain or C domain PTSD symptoms were identified by at least one item per domain scored with ‘moderate’ or higher. Participants positive for the D or E domain PTSD symptoms were identified by at least two items per domain scored with ‘moderate’ or higher. Significant PTSD symptoms where assumed in participants screened positive for at least one of the B, C, D or E PCL-5 domains (39).

Traumatic events before the accident were assessed with the DIA-X tool (42). Flashbacks frequency was surveyed as none, > 1/year and > 1/month. Smoking was surveyed as a single yes/no question. Problematic alcohol use was investigated with the CAGE tool (43). Data on the type of the accident mountain sport, injury diagnosis, severity (AIS: abbreviated injury scale) (44) and location, hospitalization, surgery and number of surgical ICD-10 diagnoses were extracted from electronic patient’s records.

The training and test participant subsets (3:1 size ratio) were obtained by random splitting which minimized differences in in sociodemographic, medical history, clinical and accident- and injury-related variables assessed by Gower distance (**Figure 1**). The training subset size (n = 230) was sufficient for clustering analysis as assessed by Hopkins metrics of 0.74 indicative of substantial spontaneous clustering tendency (45).

## Analysis endpoints

The primary analysis endpoint was assessment of mental health of mountain accident victims by clustering using standardized psychometric tools for symptoms of anxiety, depression, panic, persistent somatic symptoms, quality of life, resilience, sense of coherence, post-traumatic growth and PTSD. The secondary analysis endpoints were (1) to compare demographic, socioeconomic and clinical characteristics between the mental health clusters of mountain accident victims and (2) to identify patients at risk of post-traumatic mental disorders based on explanatory variables available during early medical treatment of the mountain sport accident.

## Statistical analysis

Details on statistical analysis are provided in **Supplementary Methods**

Statistical analysis was done with R version 4.2.3. Numeric variables are displayed as medians with interquartile ranges. Categorical variables are presented as percentages and counts. Differences in numeric variables were analyzed by Mann-Whitney or Kruskal-Wallis test with r or effect size statistics. Differences in categorical variable distribution were assessed by test with Cramer V effect size statistic (46).

The training subset was clustered in respect to normalized median-centered psychometric scores by partition around medoids with cosine distance (47,48). This algorithm had a good explanatory performance (ratio of between-cluster sum of squares to total sum of squares), separation between clusters (average silhouette width) (49) and the superior accuracy in 10-fold cross-validation (50) as compared with the hierarchical clustering and KMEANS algorithms. The k = 3 cluster number choice was based on the bend of within-cluster sum of squares curve and maximal mean silhouette statistic (45,49). The training subset observations were assigned to the clusters with an inverse distance-weighted 27-nearest neighbor classifier.

Multi-parameter machine learning classifiers of the mental health cluster assignment were trained with the canonical random forest algorithm (51,52), regularized neural network with a single hidden layer (53), support vector machine algorithm with radial kernel (54,55), recursive partitioning (56,57), multinomial elastic net regression (58,59), and conditional random forest algorithm (60–62). The cluster assignment was predicted for the test subset and the classifiers’ performance at predicting the cluster assignment was assessed by the accuracy and statistics, Brier score as well as sensitivity and specificity of predicted assignment to the post-traumatic stress cluster (63–65).

# Results

## Characteristic of the study cohort

The study collective consisted of victims of mountain sport accidents which happened in Tyrol, Austria, a renowned and popular alpine touristic region. In- and outpatient adult survivors of mountain sport accidents and treated at the Department of Orthopedics and Traumatology at Medical University of Innsbruck (Tyrol, Austria) between 1st January 2018 and 31st December 2020 were invited to participate (n = 4559). Among the invited patients, 387 completed the study survey and 307 individuals with the complete psychometric data set were analyzed (overall analysis inclusion rate: 6.7%, **Figure 1**, **Supplementary Tables S1** - **S3**). The median time between the trauma center admission and survey completion was 1343 days (interquartile range: 804 - 1441 days). As compared with the analyzed participants, patients who did not respond to the study invitation were characterized by a higher frequency of biking accidents, lower rate of alpine ski/snowboard accidents, less severe injury, lower hospitalization and surgery rates, and less surgery diagnoses (**Supplementary Table S4**). The survey participants excluded from the analysis due to missingness of psychometric data had significantly lower income, less severe injuries, more frequent injuries of the upper limbs, less frequently required hospitalization or surgery, and suffered less frequently from persistent physical health consequences of the accident than the analyzed participants (**Supplementary Table S5**). Effect sizes of the differences between the included and excluded participants were weak (V 0.22 or r 0.15).

The analyzed participants were predominantly middle-aged (median: 51, interquartile range: 33 to 60 years) and 45% of them were females. The vast majority had secondary or tertiary education grade (83%) and were professionally active (68%). Less than 8% of participants worked in a trauma-exposed or mountain sport profession. High annual household incomes of 45000 Euro was reported by 42% of participants. Less than 10% of participants were smokers or at risk of problematic alcohol use. Pre-existing physical disorders were reported by 15% of participants with cardiovascular, neurological and metabolic illness being the most frequent. Four of ten participants had experiences by or witnessed a traumatic event prior to the accident, 10.4% participants experienced two or more traumatic events. Mental disorders prior the accident affected 5.2% of the cohort with affective (2.3%) and somatoform disorders (1.6%) as the leading pre-existing mental conditions (**Table 1**).

Mountain sport accidents in the past were reported by 38% of participants. Most of the investigated accidents occurred during alpine skiing, snowboarding or cross-country skiing (64%) followed by biking (16%) and classical mountain sports such as climbing, hiking, mountaineering or back-country skiing (NA%). One-third of participants were alone during the accident (32%) and, in most cases, were the sole culprit (77). Professional rescue service was involved in 29% of the accidents. In 35% of participants the injury was moderate (AIS 2) and in 28% severe-to-critical (AIS 3). Limb injuries were the most common followed by head and face (**Supplementary Figure S1A**). Hospitalization and surgery rates following the accident were 26% and 14%, respectively. Psychological or psychiatric support after the accident was provided to 9.1% individuals. A subset of participants (get\_percent(ptsd$dataset, 'psych\_support\_need')$percent['yes']%), who had not received it, declared need for psychological support following the accident. Despite persisting physical consequences of the accident, which affected 37% of participants and flashbacks during mountain sport at the time of the questionnaire completion in 40% of the cohort, most participants returned to the same mountain sport following the accident (85%). Yet, 65% described their behavior during mountain sport as more cautious (**Table 2**).

At least one diagnostic criterion of PTSD defined by the PCL-5 tool (B, C, D or E) were met by 19% of participants. The domain B PTSD symptoms were the most common (11%) and the domain D symptoms were the least frequent (5.2%). Solely 4 patients (1.3%) were screened positive for all four diagnostic criteria of PTSD (**Table 3**, **Supplementary Figure S1BC**). Clinically relevant symptoms of anxiety (2.3), depression (5.5%) and somatic symptoms (4.9%) were rare in this cohort consisting of 68% highly resilient individuals (**Table 3**).

For clustering and modeling, the cohort was split into the training (n = 230) and test subset (n = 77). Significant differences of weak effect size between these subsets concerned resilience class distribution and scores of quality of life (**Supplementary Table S6**).

## Three clusters of mental response in sport accident victims

To explore symptoms of PTSD and further facets of mental health following mountain sport accidents, we subjected the participants to partition around medoids clustering in respect to a broad range of psychometry scores (47,48) (**Supplementary Table S2**). Three mental clusters: ‘neutral’, ‘PTG’ (post-traumatic growth) and ‘PTS’ (post-traumatic stress), named after their key mental characteristic were identified in the training subset (**Supplementary Figure S3**). Subsequently, the mental cluster assignment could be validated in the test subset as evident from comparable fractions of explained clustering variance (training: 0.55, test: 0.52), comparable average silhouette statistics (training: 0.3, test: 0.26) (49), comparable cluster sizes, good visual cluster separation and high similarity between the corresponding clusters in the training and test cohort subsets (**Supplementary Figures S4 - S6**).

The mental clusters were of approximately equal size. The neutral cluster was characterized by low levels of anxiety, depression, panic, somatic symptoms, post-traumatic stress and post-traumatic growth along with high rating of sense of coherence, resilience and quality of life. The PTG cluster demonstrated similarly low scores of major mental health disorders, high resilience and sense of coherence. Its key characteristic were the highest levels of post-traumatic growth. The remaining PTS cluster displayed the highest scores of for anxiety, depression, panic disorder, somatic symptoms and post-traumatic stress as well as poor sense of coherence, and low resilience and low quality of life. Post-traumatic growth scores in the PTS cluster were higher than in neutral but lower than in PTG cluster participants (**Figure 2**, **Supplementary Table S7**). Consequently, clinically relevant symptoms of anxiety (PTS: 6.4%), depression (PTS: 14%) and somatic symptoms (PTS: 10%) were present virtually only in the PTS cluster. Furthermore, frequencies of low (PTS: 42%) and moderate resilience classes (PTS: 28%) peaked in the PTS cluster. Finally, the frequency of flashbacks, PTSD symptoms specified by the B, C, D and E PCL-5 domains and the frequency of patients meeting at least one PCL-5 PTSD diagnostic criterion (PTS: 35%) were the highest in PTS cluster individuals (**Figure 3**, **Supplementary Table S7**).

## Demographic, socioeconomic and clinical background of the mental health clusters

Among 48 investigated demographic, socioeconomic, clinical, accident- and recovery-related variables, only 6 features (age, pre-existing physical illness, pre-existing mental disorder, psychological support need, persistent physical health consequences of the accident, and caution during sport activity) were found to differ significantly between the mental clusters. The effect size of these differences was weak (**Supplementary Table S8**).

In more detail, PTS cluster patients were the youngest of all participants and had the highest frequency of pre-existing mental conditions. The neutral cluster was in turn substantially enriched in males, and tertiary education and high income individuals; these effects were, however not significant. Participants suffering from pre-existing somatic conditions were significantly enriched in the PTG and PTS clusters. A similar, yet not significant tendency was observed for frequency of prior traumatic events, which was higher in the PTG and PTS clusters as compared with neutral cluster patients. There were no substantial differences in frequency of participants with trauma-risk professions and employment structure between the clusters (**Figure 4**, **Supplementary Figure S7**). Participants reporting being alone during the accident, the only culprit of the accident, and requiring comrade or professional rescue were enriched in the PTG cluster. In turn, frequency of self-rescuers tended to be the highest in the neutral cluster. These differences in accident and rescue circumstances were not significant. We could not observe any substantial differences in accident season, mountain sport type, and numbers of injured persons between the clusters (**Figure 5A**, **Supplementary Figure S7**). There were no significant differences in severity and injury and its location between the clusters. However, moderate-to-severe injuries (AIS 2), hospitalization and surgery rates were higher in the PTG and PTS clusters as compared with neutral cluster patients (**Figure 5**).

There were no significant differences in rates of psychological or psychiatric support after the accident between the clusters. Among PTG and PTS cluster individuals, 8.5% and 14%, respectively, reported need for psychological support following the accident as compared with none in the neutral cluster. Frequency of participants suffering from persistent physical health consequences of the accident was the highest in the PTS cluster (PTS: 52%, PTG: 32%, neutral: 27%). Analogically, PTS cluster patients reported the highest rates of cautious behavior during mountain sport following the accident (PTS: 78%, PTG: 67%, neutral: 49%). By contrast, percentages of participants who returned to the same mountain sport after the accident were comparable between the mental clusters (**Figure 6**).

## Prediction of the mental cluster assignment by demographic, socioeconomic and accident-related factors

Finally, we intended to model the mental cluster assignment with demographic, socioeconomic, clinical and accident-related factors available during acute medical management of the accident (**Supplementary Table S9**) with seven popular machine learning algorithms: the random forests (51,52), neural networks (53), support vector machines (55), recursive partitioning (56), discriminant analysis (66,67), elastic net regression (58,59), and conditional random forests (60–62) (**Supplementary Table S10**). Such models would enable early identification of mountain sport accident victims at risk of mental health problems.

The cluster assignment models employing early predictors demonstrated a moderate-to-excellent prediction performance in the training subset of the study cohort (64% - 100%% of correctly assigned observations, Cohen’s : 0.45 - 1, Brier score: 0.018 - 0.57). However, their accuracy in cross-validation and in the test subset was poor (test: 34% - 47%% of correctly assigned observations, Cohen’s : 0.018 - 0.21, Brier score: 0.65 - 0.96). Concerning the early identification of the vulnerable PTS cluster patients, the conditional random forest, random forest and support vector machine models were able to differentiate PTS cluster patients from the pooled neutral + PTG cluster subset with the best, at least 48% sensitivity in the test subset of the study cohort (**Figure 7**, **Supplementary Table S12**). Pre-existing mental disorder or physical illness, hospitalization and surgery, injury severity, age, rescue mode, education, annual income, and traumatic events in the past were among the most important explanatory factors employed by these models (**Supplementary Figure S8**). Of note, inclusion of follow-up-related variables such as psychological support, physical health consequences or caution during sport activity in the machine learning models of the mental cluster assignment did not improve their accuracy in cross-validation or the test subset of the study cohort (test: 36% - 46%% of correctly assigned observations, Cohen’s : 0.049 - 0.2, Brier score: 0.64 - 0.92).

# Discussion

Herein, we cross-sectionally explored mental health in victims of mountain sport accidents treated at a tertiary trauma center at median 44 months after the trauma center admission. We identified three approximately equally sized subsets of participants with distinct mental health characteristic: (1) the neutral mental health cluster, (2) the PTG cluster characterized by predominantly salutatory reaction to the accident manifested by post-traumatic growth, and (3) the PTS cluster hallmarked by symptoms of PTSD, anxiety, depression, panic disorder, persistent somatic symptoms as well as low resilience, quality of life and sense of coherence. PTS cluster patients were characterized by lower age, more frequent pre-existing physical and mental conditions, self-reported need for psychological support, long-term physical health consequences of the accident and cautious behavior during sport. The PTS cluster was also substantially enriched in hospitalized and surgery patients. However, even with robust machine learning algorithms we could not establish a reliable model to identify PTS cluster patients at risk of long-term mental health problems with data available during acute medical management of the mountain sport accident.

To the best of our knowledge this is the first study evaluating a broad palette of mental features including symptoms of anxiety and depression, somatic symptoms, resilience, post-traumatic growth and symptoms of PTSD in survivors of mountain sport accidents. This population is of special interest because, on one hand, mountain sport is generally considered beneficial for mental health (2,3). On the other hand, mountain sport is associated with specific individual physical and mental traits, and bears potential of danger (5,6). Studies conducted on mountain guides and mountain rescue personnel, showed that 71% - 78% of them experienced a traumatic event (28,29). Intriguingly, the frequency of PTSD symptoms in those populations was estimated for 1% - 5.9% (28,29,31), which was comparable to the general population (14,15,68,69) and, particularly, lower than in other potentially vulnerable groups such as emergency workers (70). By contrast, a recent Swiss study found a prevalence of PTSD in up to 22% of mountain rescuers once differentiating between clinical interviews and self-reporting of symptoms for the assessment of PTSD (31). Concerning mountain accidents, survivors of avalanches were affected by acute and long-term PTSD symptoms such as hyperarousal or sleep disorders at rates between 11 - 16% (27,30). This figure is comparable with 19% participants of our study screened positive for at least one of of the PTSD symptom domains defined by the PCL-5 tool (39). Of note, the frequency of at least one PCL-5 PTSD symptom in our cohort recruited among patients of a trauma department is similar to the 11.8% - 26.6% prevalence reported in literature for emergency department or acute trauma patients (16,17,19,21). However, in our cohort, solely 1.3% of participants demonstrated concomitant PCL-5 domain B, c, D and E symptoms suggestive of fully manifest PTSD. Resilience has been proposed as a protective trait against mental health deterioration following trauma (25,26) and high resilience levels in mountain rescuers may be explain low prevalence of PTSD in this population despite trauma exposure (29). Two-thirds of our study participants were classified as highly resilient (36). This observation may hence explain the low rate of manifest PTSD as well as lower frequencies of clinically relevant symptoms of anxiety and depression in our cohort than estimated for the general Austrian population (71). The high resilience in the study cohort may also pertain to the high rating of quality of life (EUROHIS, median: 4.4, interquartile range: 4 to 4.6) comparable to the general western European population (38). Post-traumatic growth represents a salutogenic reaction to a traumatic event with positive changes in personality, self-assurance, experience and inter-personal relationships (24), which may overlap with resilience and PTSD symptoms (26,72). This phenomenon was evident also in our study, where PTG cluster participants were characterized by a pronounced post-traumatic growth and good resilience scoring, which was however paralleled by flashbacks and single PTSD symptoms.

By semi-supervised clustering, we identified mountain sport accident victims with co-existing symptoms of PTSD, depression, anxiety, somatic symptoms, as well as low sense of coherence and quality of life. Those patients assigned to the PTS subset may represent a potentially clinically relevant risk group of post-traumatic mental disorders. The psychometric characteristic of the PTS cluster corresponds to the multi-faceted mental symptoms described for PTSD individuals (7,9–11). Regarding early predictors of mental health problems, the PTS cluster was characterized by a significantly younger age as well as high rates of pre-existing physical and mental disorders. It was also substantially enriched in females, low-to-moderate income patients, individuals requiring comrade or professional rescue, hospitalization and surgery as compared with neutral cluster patients. Of note, female gender (21,73–75), young age at traumatization (19,76), low income (77) and pre-existing mental disorders (18,75,78) has been proposed as risk factors of PTSD. The recovery features of the PTS cluster were the highest rates of self-reported need for psychological support, persistent physical health consequences of the accident and the highest percentage of more cautious behavior during sport activity as compared with the neutral or PTG cluster. However, differences in the early or follow-up variables between the mental clusters in the study cohort were only of weak effect size, which underlines the lack of strong predictive markers and moderate explanatory power of published models predicting post-traumatic mental problems (17,18,21,79–81). PTSD risk has been previously associated with injury severity, head injuries, hospitalization length and pain (75,79,82). We could not establish any link between the clusters and, in particular, the PTS cluster with objective injury severity measured with the AIS scale (44) or injury location. Intriguingly, subjective injury severity, which was not surveyed in our cohort, was shown to be a stronger predictor of PTSD symptoms than objective injury severity (83). This phenomenon together with the longer survey - treatment time interval than in most other studies and differences in composition of the study sample, may explain the lacking effect of injury on later mental disorders in our collective. Importantly, the percentage of participants having received psychological or psychiatric support after the accident was generally low (9.1%) in the study cohort and did not differ between the mental clusters. Hence, it is unlikely that psychological or psychiatric intervention had any impact on classification of the participants.

Early identification of trauma patients at risk of development of PTSD or follow-up mental health disorders has previously been tackled by diverse machine learning algorithms (17–19,79). In our hands, none of seven machine learning algorithms employing different mathematical principles, random forest, neural network, support vector machines, recursive partitioning, conditional random forest, discriminant analysis or elastic net regression, was able to reliably predict the mental cluster assignment based on 40 demographic, socioeconomic, clinical and accident-related variables available during acute medical treatment of the mountain sport accident. This phenomenon is likely attributed to the lacking strong non-mental explanatory variables differentiating between the mental clusters and, of clinical importance, highly specific markers of post-traumatic stress patients. Interestingly, inclusion of peri-traumatic mental symptoms like PTSD features, flashbacks, hyperarousal, or subjective need for support was shown to be crucial for optimal prediction of long-term mental disorders or PTSD during recovery (17–19,21,79,83). Unfortunately, such variables were not available in our cohort investigated at least six months after the accident.

# Limitations

Our study bears limitations. The overall analysis inclusion rate was low and, as indicated by comparison of the excluded and analyzed participants, the results were potentially confounded by a selection bias towards better patients with higher social status and more severe injuries. Although the key of the mental clusters, post-traumatic growth and PTSD, were clearly associated with trauma (8,24,39), the mental cluster assignment could have been affected by other events than the sport accident. Furthermore, our data set misses important explanatory factors which may facilitate distinction between the mental clusters such as rehabilitation need or ability to work. Analogically, due to the cross-sectional design of the study, we were not able to assess peri-traumatic mental disorder symptoms, which has been proven crucial for identification of vulnerable patients (17–19,21,79,83). Finally, a longitudinal survey may have helped to assess individual trajectories of mental health reaction to the mountain sport accident.

# Conclusions and outlook

Our study represents the first attempt to characterize post-traumatic stress and further facets of mental health following mountain sport accidents. We identified symptoms of mental health impairment in roughly one third of the victims. However, we could not identify robust predictors for post-traumatic stress among variables available during early medical treatment. Hence, considering the increasing popularity of mountain sports, low-threshold information and psychological support for trauma department patients treated seems the most appropriate strategy for successful multi-disciplinary medial management of mountain sport accidents. Such information campaign can include informative leaflets, additional information in the discharge letter, as well as websites or mobile applications explaining frequent warning signs and symptoms of post-traumatic stress disorder and providing contact data for points of psychological support. We are currently implementing such measures at our hospital.

# Data and code availability

An R data (RData) file with anonymized patient data will be made available upon request to the corresponding author. The study analysis pipeline is available at <https://github.com/PiotrTymoszuk/mental_accident>.

# Tables

Table 1: Demographic and socioeconomic characteristic of the study cohort. Numeric variables are presented as medians with interquartile ranges (IQR). Categorical variables are presented as percentages and counts within the complete observation set.

| **Variablea** | **Statistic** |
| --- | --- |
| Participants, n | 307 |
| Hospital visit – survey time, days | 1300 [IQR: 800 - 1400] range: 390 - 1600 |
| Age, years | 51 [IQR: 33 - 60] range: 18 - 82 |
| Age class, years | 16-30: 20% (n = 61) 31-65: 66% (n = 202) >65: 14% (n = 44) |
| Sex | female: 45% (n = 137) male: 55% (n = 170) |
| Residence in the Alps | 73% (n = 225) |
| Education | primary: 16% (n = 49) secondary: 38% (n = 115) tertiary: 45% (n = 136) |
| Employment | employed: 68% (n = 210) unemployed: 3.6% (n = 11) student: 10% (n = 32) retired: 18% (n = 54) |
| Sport profession | 5.2% (n = 16) |
| Trauma-risk profession | 7.2% (n = 22) |
| Income/year | no income: 21% (n = 63) < 30000 EUR: 18% (n = 56) 30000 - 45000 EUR: 19% (n = 59) ≥ 45000 EUR: 42% (n = 129) |
| Smoking | 7.8% (n = 24) |
| Problematic alcohol use (CAGE ≥2) | 9.4% (n = 29) |
| Pre-existing physical illness type | none: 85% (n = 260) CVD: 2.9% (n = 9) neurological: 1.3% (n = 4) metabolic: 1.3% (n = 4) pulmonary: 0.65% (n = 2) cancer: 0.65% (n = 2) rheumatoid: 0.33% (n = 1) skin: 0.33% (n = 1) other: 7.8% (n = 24) |
| Number of prior traumatic events/DIA-X | none: 60% (n = 183) 1: 30% (n = 92) 2: 7.5% (n = 23) 3+: 2.9% (n = 9) |
| Pre-existing mental disorder | 5.2% (n = 16) |
| Affective disorder | 2.3% (n = 7) |
| Personality disorder | 0.33% (n = 1) |
| Post-traumatic stress disorder | 0.65% (n = 2) |
| Somatoform disorder | 1.6% (n = 5) |
| Anxiety disorder | 0.65% (n = 2) |
| Attention-deficit hyperactivity disorder | 0.33% (n = 1) |
| Addiction | 0.33% (n = 1) |
| Bulimia nervosa | 0.33% (n = 1) |
| aCAGE: Cut/Annoyed/Guilty/Eye substance abuse scale; DIA-X: Diagnostic Expert System, traumatic event score. | |

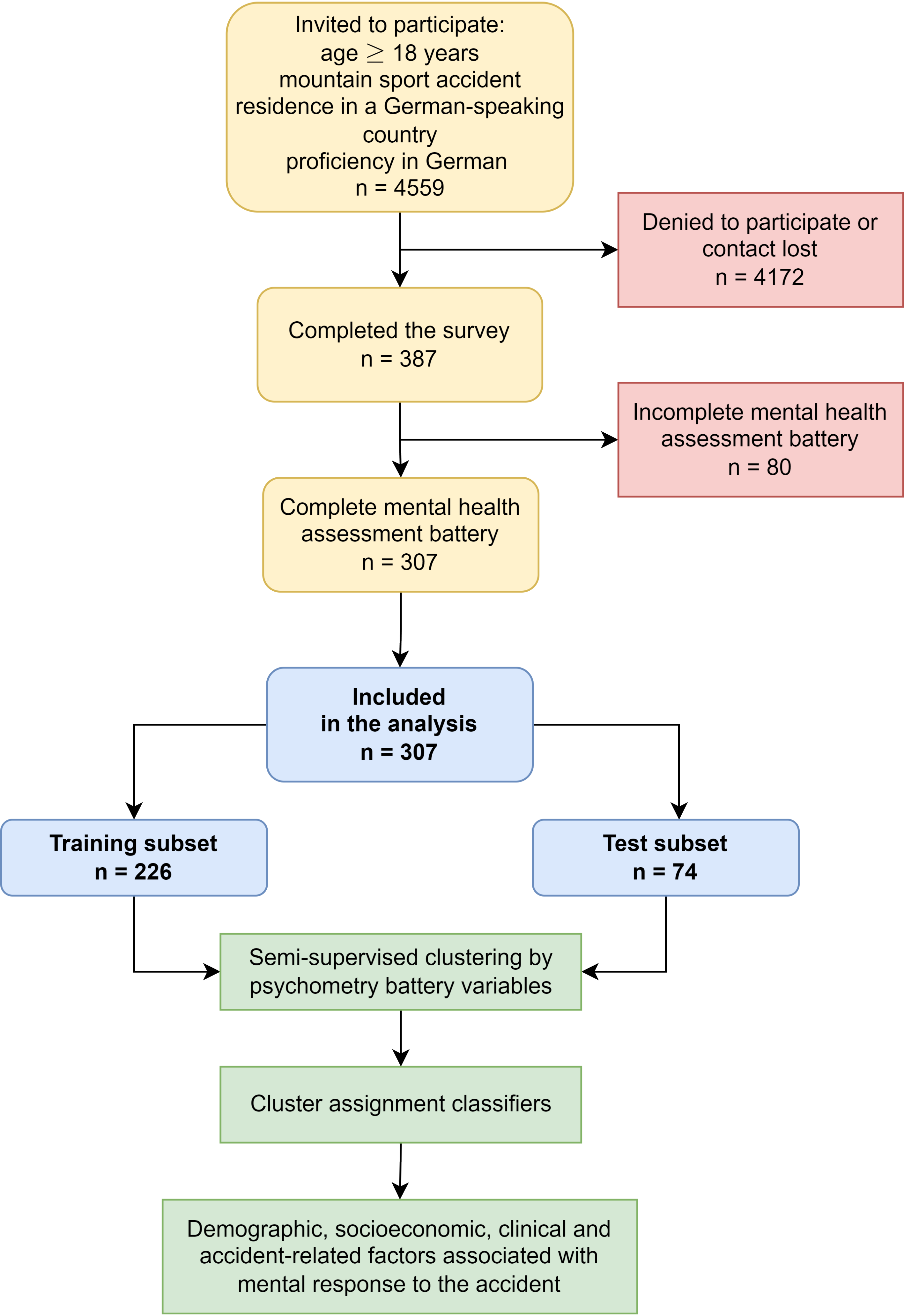
Table 2: Characteristic of the sport accident, injury, psychological management and accident consequences. Numeric variables are presented as medians with interquartile ranges (IQR). Categorical variables are presented as percentages and counts within the complete observation set.

| **Variable** | **Statistic** |
| --- | --- |
| Prior sport accidents | 38% (n = 118) n = 307 |
| Sport typea | ski/snowboard/cross-country: 64% (n = 197) sledding: 3.9% (n = 12) climbing/hiking/mountaineering/skitour: 14% (n = 42) biking: 16% (n = 48) other: 2.6% (n = 8) n = 307 |
| Alone during the accident | 32% (n = 97) n = 307 |
| Responsible for the accident | self: 77% (n = 237) non-self: 23% (n = 70) n = 307 |
| Injured persons | only self: 64% (n = 195) self and partner: 3.6% (n = 11) 3+ persons: 1.3% (n = 4) no information: 32% (n = 97) n = 307 |
| Rescue | self: 50% (n = 155) comrade: 21% (n = 63) rescue team: 29% (n = 89) n = 307 |
| Injury severity class, AIS | 1: 37% (n = 108) 2: 35% (n = 103) 3+: 28% (n = 83) n = 294 |
| Hospitalizedb | 26% (n = 80) n = 307 |
| Surgery | 14% (n = 43) n = 307 |
| Psychological or psychiatric support received after the accident | 9.1% (n = 28) n = 307 |
| Self-reported need for psychological support after the accident | 7.5% (n = 23) n = 307 |
| Persisting physical consequences of the accident | 37% (n = 115) n = 307 |
| Returned to the same mountain sport after the accident | 85% (n = 262) n = 307 |
| Behavior during mountain sport after the accident | no change: 35% (n = 106) more cautious: 65% (n = 199) less cautious: 0.65% (n = 2) n = 307 |
| Flashbacks during mountain sport | none: 60% (n = 185) > 1/year: 22% (n = 68) > 1/month: 18% (n = 54) n = 307 |
| aski/snowdoard/cross-country: alpine skiing, snowboarding and cross-country skiing sledding: sledding or bobsled climbing/hiking/mountaineering: hiking, rock and ice climbing, mountaineering, skitouring biking: mountainbike, tour and road cycling. | |
| bAIS: abbreviated injury scale. | |

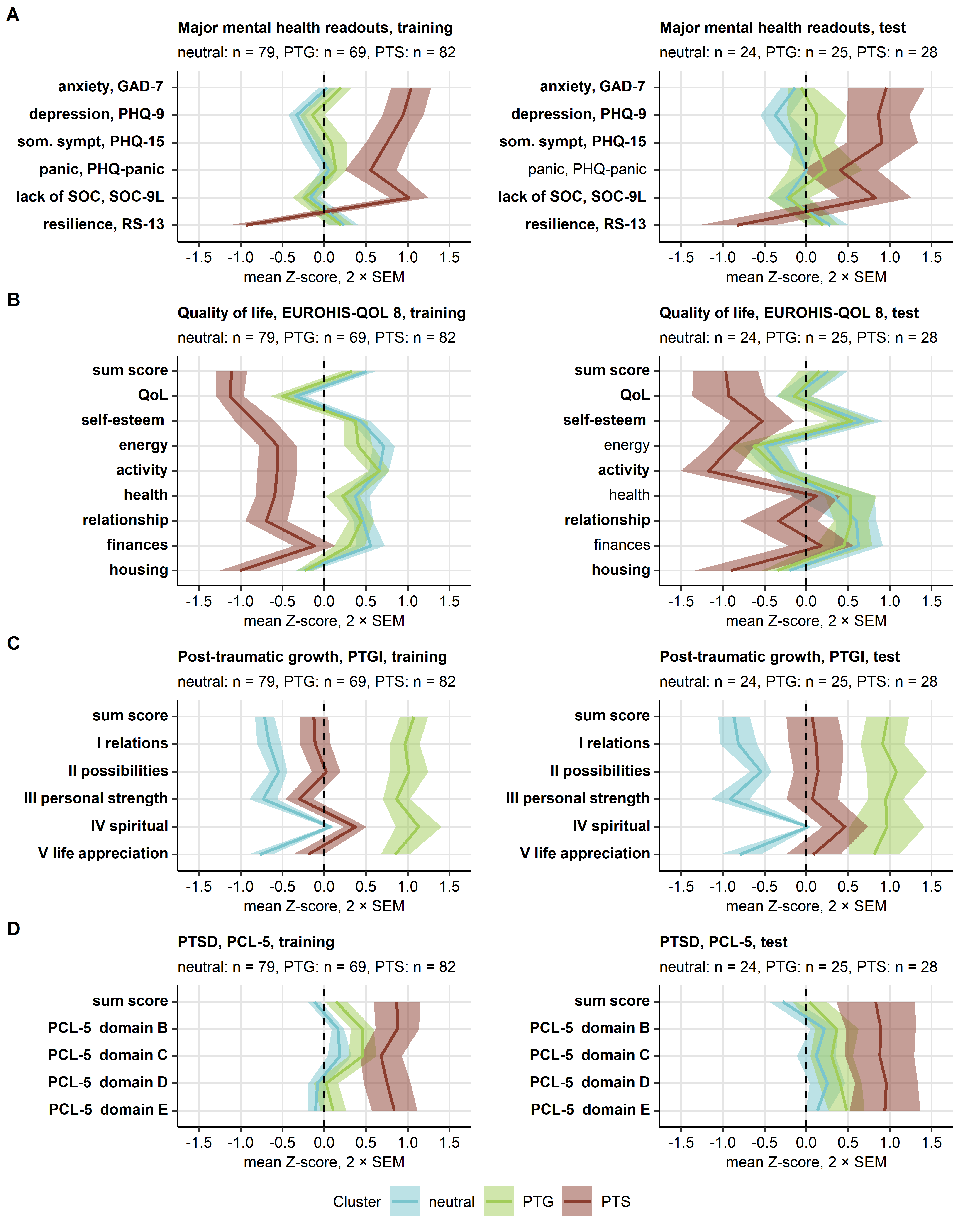
Table 3: Mental health characteristic of the study participants at survey completion. Numeric variables are presented as medians with interquartile ranges (IQR). Categorical variables are presented as percentages and counts within the complete observation set.

| **Variablea** | **Statistic** |
| --- | --- |
| Participants, n | 307 |
| GAD-7 score | 1 [IQR: 0 - 3], range: 0 - 15 |
| Anxiety symptoms (GAD-7 ≥10) | 2.3% (n = 7) |
| PHQ-9 score | 2 [IQR: 1 - 5], range: 0 - 16 |
| Depression symptoms (PHQ-9 ≥11) | 5.5% (n = 17) |
| PHQ-15 score | 2 [IQR: 1 - 4], range: 0 - 23 |
| Somatic symptoms (PHQ-15 ≥11) | 4.9% (n = 15) |
| EUROHIS-QOL 8 mean score | 4.4 [IQR: 4 - 4.6], range: 2 - 5 |
| SOC-9L score | 19 [IQR: 16 - 25], range: 10 - 49 |
| RS13 score | 78 [IQR: 70 - 85], range: 15 - 91 |
| RS13 resilience class | low: 18% (n = 56) moderate: 14% (n = 42) high: 68% (n = 209) |
| PTGI score | 32 [IQR: 16 - 48], range: 0 - 100 |
| PCL-5 score | 3 [IQR: 1 - 7], range: 0 - 44 |
| PTSD+ (at least one PCL-5 domain) | 19% (n = 58) |
| aGAD-7: 7-item general anxiety disorder scale; PHQ: patient health questionnaire; EUROHIS-QOL 8: 8-item EUROHIS project quality of life scale; SOC-9L: Leipzig 9-item sense of coherence questionnaire; RS13: 13-item resilience scale; PCL-5 DSM-5: PTSD checklist for DSM-5; PTGI: post-traumatic growth inventory; PTSD: post-traumatic stress disorder. | |

# Figures

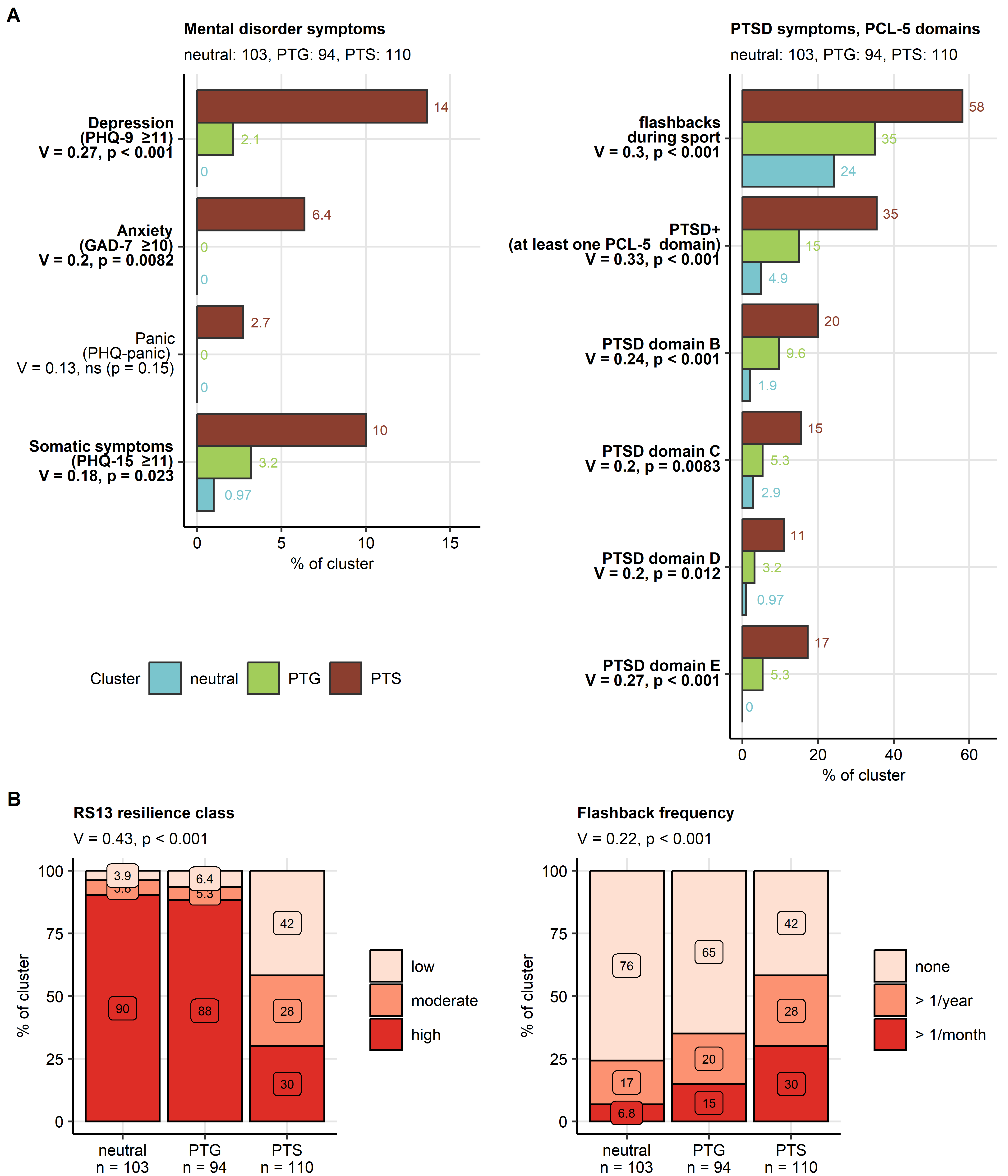


**Figure 1. Flow diagram of the analysis inclusion process.**



**Figure 2. Scores of mental disorder symptoms, sense of coherence, resilience, quality of life, post-traumatic growth, and post-traumatic stress disorder in the mental clusters.**

*Study participants in the training subset of the cohort were assigned to the neutral, PTG (post-traumatic growth) and PTS (post-traumatic stress) mental clusters defined in respect to psychometric scores by the partition around medoids (PAM) algorithm. Study participants in the test subset of the cohort were assigned to the mental clusters by the inverse distance weighted 7-nearest neighbors classifier. Differences in the cluster-defining psychometric scores between the clusters were assessed by Kruskal-Wallis test with effect size statistic. P values were adjusted for multiple testing with the false discovery rate method. Mean normalized scores of major mental health readouts, sense of coherence and resilience (A), quality of life (B), post-traumatic growth (C) and post-traumatic stress disorder (PTSD, D) in the mental clusters of the training and test subsets of the study cohort are depicted as solid lines. Tinted regions represent 2 SEM (standard error of the mean). Numbers of observations in the clusters are displayed in the plot captions. Significant effects are highlighted in bold.* *GAD-7: 7-item general anxiety disorder scale; PHQ: patient health questionnaire; som. sympt.: somatic symptoms; EUROHIS-QOL 8: 8-item EUROHIS project quality of life scale; SOC-9L: Leipzig 9-item sense of coherence questionnaire; RS13: 13-item resilience scale; PCL-5: PTSD checklist for DSM-5; PTGI: post-traumatic growth inventory; PTSD: post-traumatic stress disorder.*



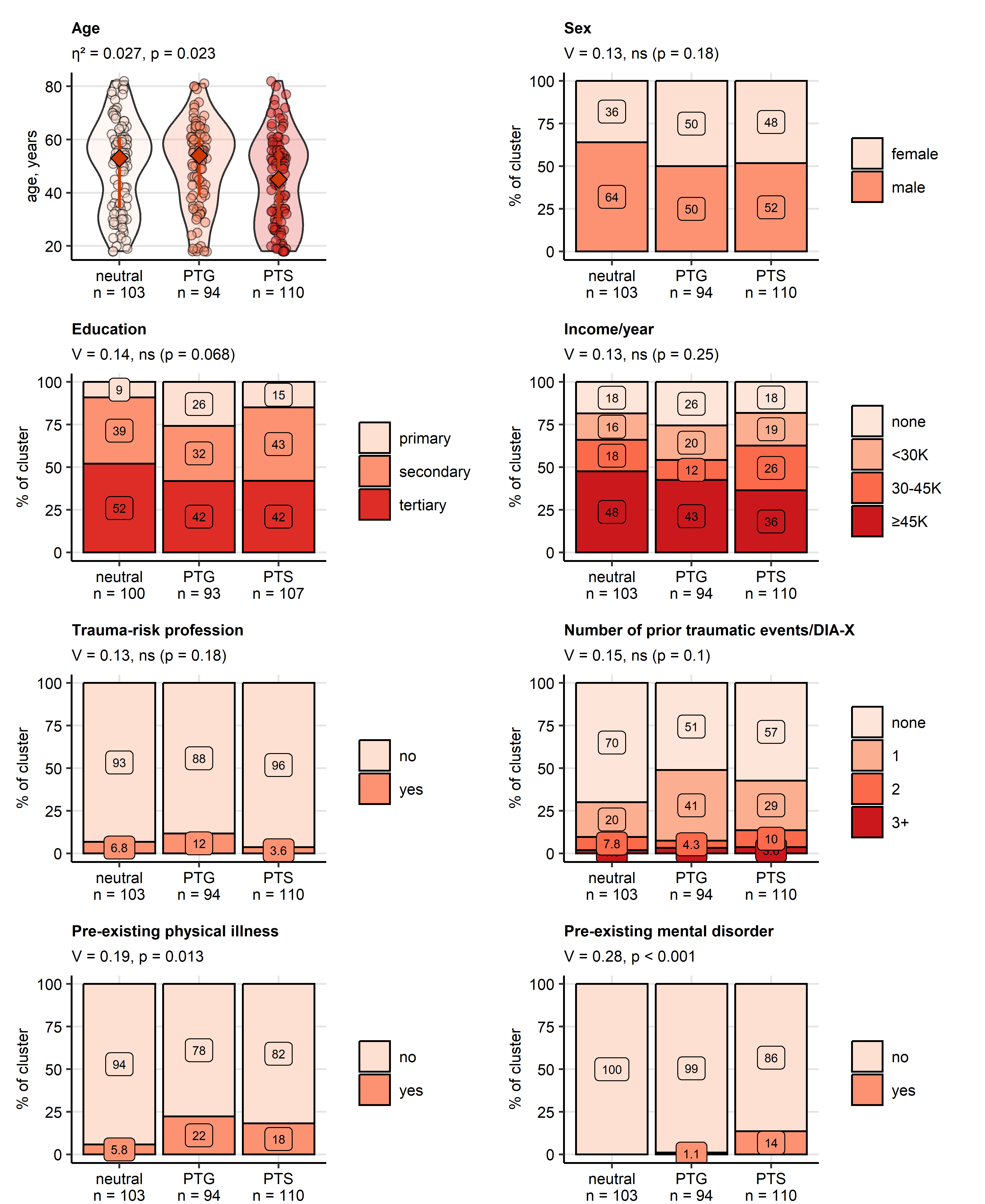
**Figure 3. Symptoms of mental disorders and resilience classes in the mental clusters.**

*Differences in frequency of mental disorder symptoms and flashbacks, and distribution of resilience classes between the mental clusters (neutral, post-traumatic growth [PTG] and post-traumatic stress [PTS]) were investigated in the entire study cohort by test with Cramer’s V effect size statistic. P values were adjusted for multiple testing with the false discovery rate method.*

*(A) Symptoms of mental disorders, presence of flashbacks during sport activity and symptoms of post-traumatic stress disorder (PTSD). Percentages of affected individuals in the mental clusters are presented in bar plots. Effect sizes and p values are indicated in the Y axes. Significant effects are highlighted in bold. Numbers of observations in the clusters are indicated in the plot captions.*

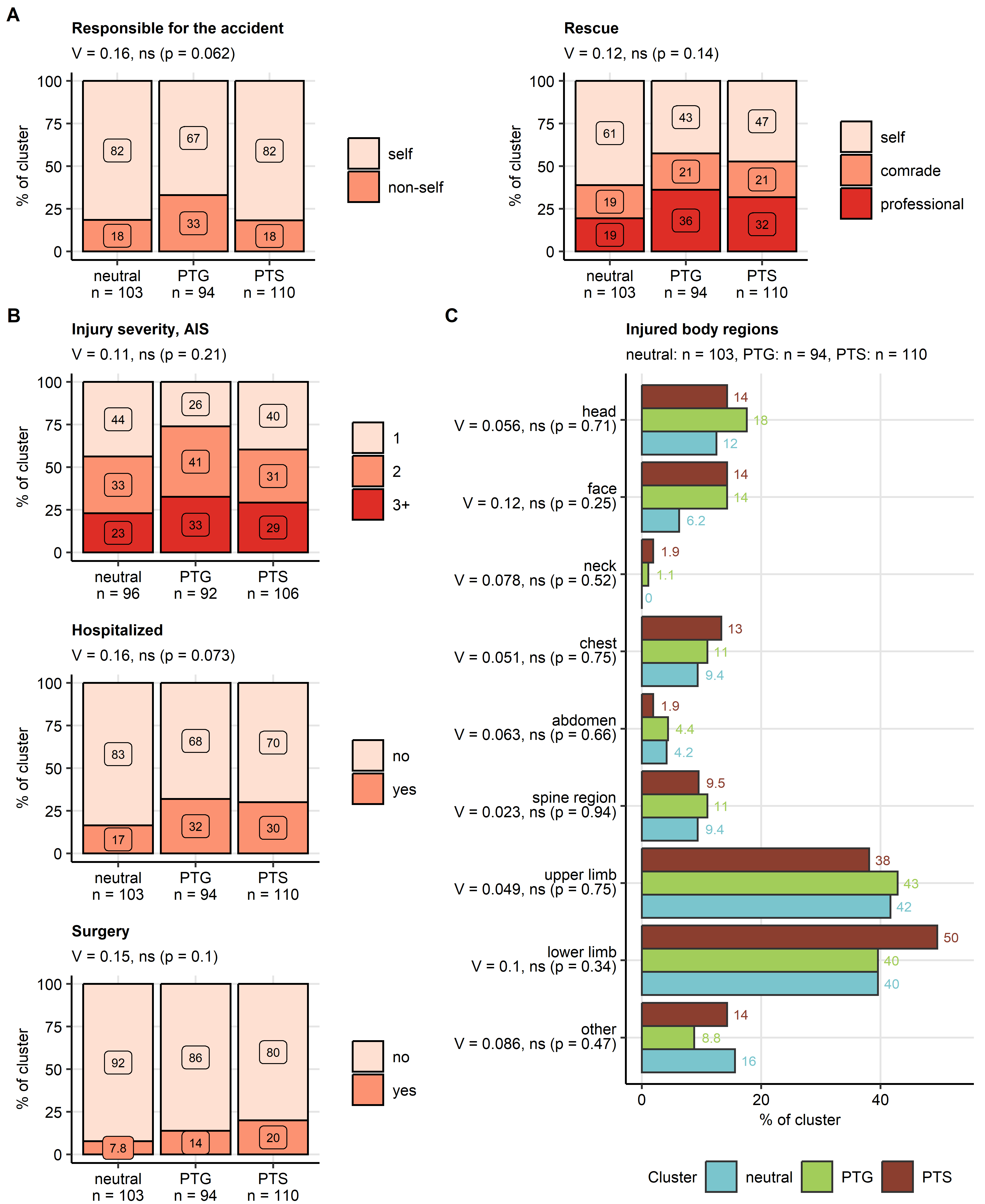
*(B) Resilience classes and frequency of flashbacks during sport activity in the mental clusters presented in stack plots. Effect sizes and p values are displayed in the plot captions. Numbers of observations in the clusters are indicated in the X axes.*

*GAD-7: 7-item general anxiety disorder scale; PHQ: patient health questionnaire; RS13: 13-item resilience scale; PCL-5: PTSD checklist for DSM-5; PTSD: post-traumatic stress disorder.*



**Figure 4. Sociodemographic and medical history characteristic of the mental clusters of accident victims.**

*Differences in age during the accident between the mental clusters (neutral, post-traumatic growth [PTG], post-traumatic stress [PTS]) were assessed in the entire cohort by Kruskal-Wallis test with effect size statistic. Differences in genders, education, annual income classes (K: 1000 Euro), percentages of participants with trauma risk profession, traumatic events in the past (DIA-X: Diagnostic Expert System, traumatic event score), as well as pre-existing physical illness and pre-existing professionally diagnosed mental disorders between the mental clusters were investigated in the entire cohort by test with Cramer’s V effect size statistic. P values were adjusted for multiple testing with the false discovery rate method. Age is presented in violin plots with single observations visualized as points and medians with interquartile ranges depicted by red diamonds and whiskers. The remaining variables are presented as percentages of the clusters in stack plots. Effect sizes and p values are displayed in the plot captions. Numbers of observations in the clusters are indicated in the X axes.*

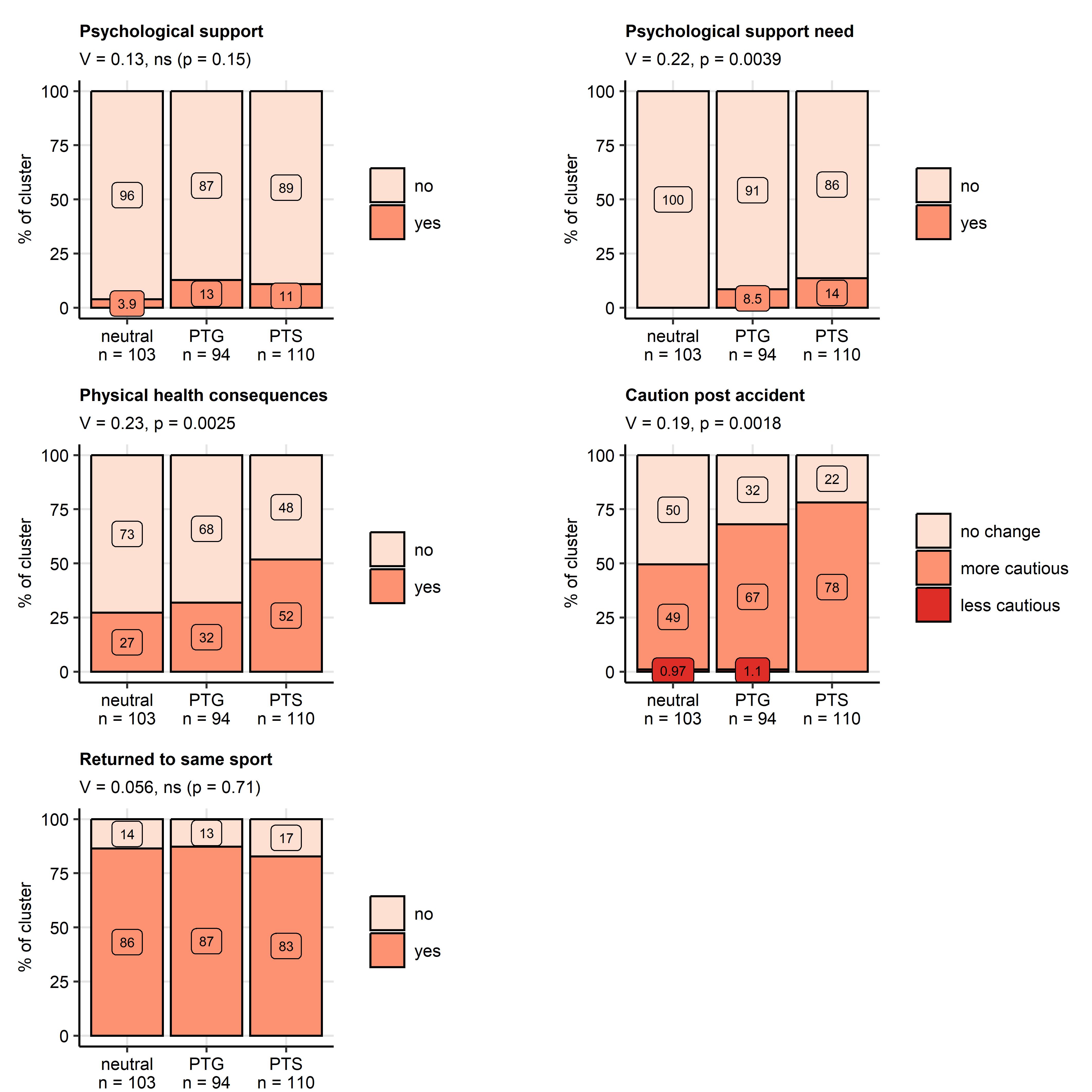


**Figure 5. Accident culprits, accident rescue, injury severity and injured body parts in the mental clusters.**

*Differences in accident culprit, rescue mode, injury severity, hospitalization and surgery rates, and injured body regions between the mental clusters (neutral, post-traumatic growth [PTG], post-traumatic stress [PTS]) were investigated in the entire cohort by test with Cramer’s V effect size statistic. P values were adjusted for multiple testing with the false discovery rate method.*

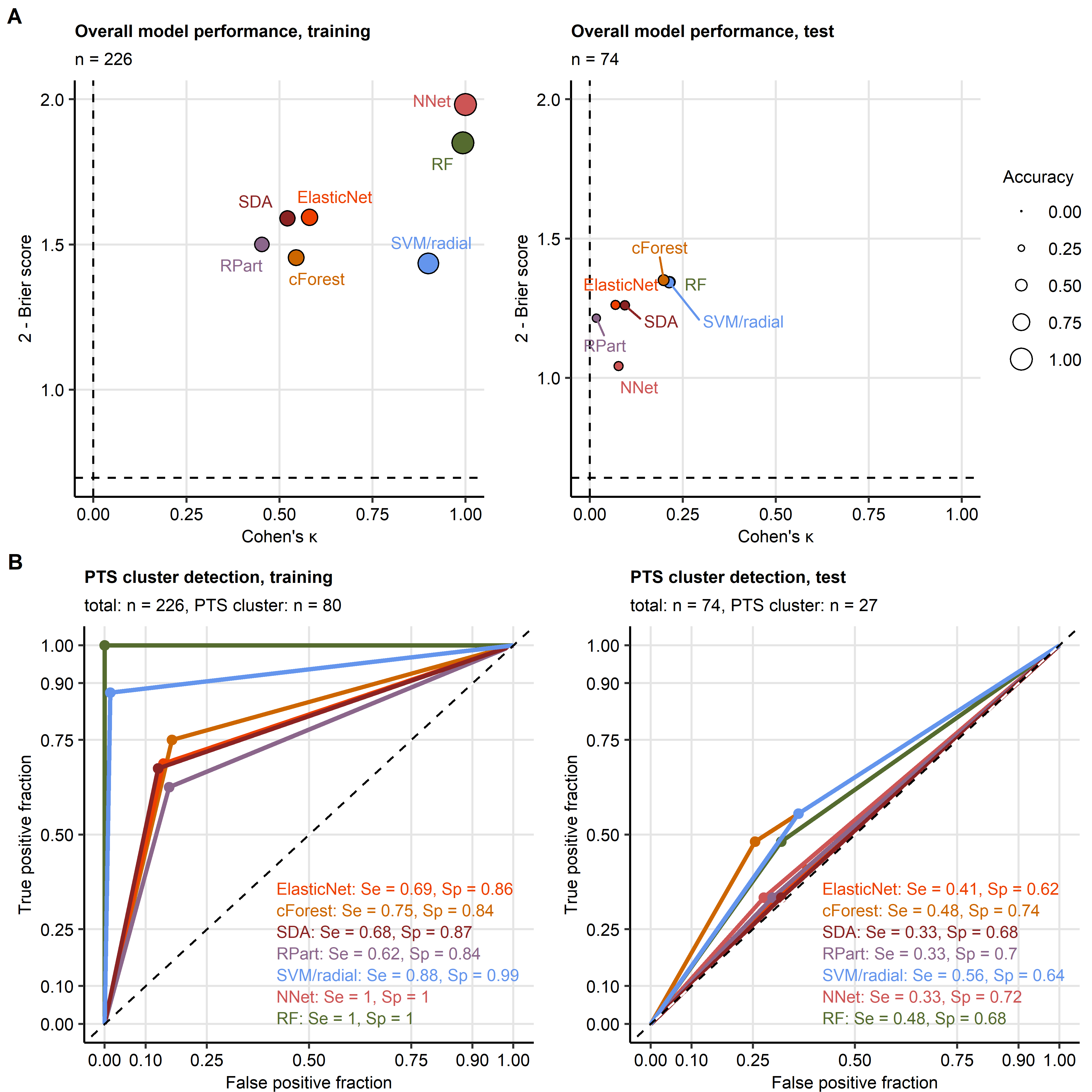
*(A, B) Percentages of self and non-self accident culprit, distribution of the rescue modes and injury severity classes (AIS: abbreviated injury scale), rates of hospitalization and surgery in the mental clusters were presented in stack plots. Effect sizes and p values are displayed in the plot captions. Numbers of observations in the clusters are indicated in the X axes.*

*(C) Percentages of injured body regions were presented in a bar plot. Effect sizes and p values are indicated in the Y axis. Numbers of observations in the clusters are displayed in the plot captions.*



**Figure 6. Psychological support and consequences of the accident in the mental clusters.**

*Differences in rates of received psychological or psychiatric support, self-reported need for psychological support, persistent physical health consequences of the accident, cautious behavior during mountain sport activity and percentages of participants having returned to the same mountain sport activity between the mental clusters (neutral, post-traumatic growth [PTG], post-traumatic stress [PTS]) were assessed in the entire cohort by test with Cramer V effect size statistic. P values were adjusted for multiple testing with the false discovery rate method. Percentages within the clusters are presented in stack plots. Effect sizes and p values are displayed in the plot captions. Numbers of observations in the clusters are indicated in the X axes.*



**Figure 7. Assignment of accident victims to the mental clusters based on explanatory factors available during acute medical management of the accident.**

*The mental cluster assignment was modeled with demographic, medical history and accident-related explanatory factors available during acute medical management of the accident. Psychometric variables used for cluster definition, mental disorder symptoms, resilience classes as well as presence and frequency of flashbacks were excluded from the explanatory factor set.*

*(A) Accuracy of the predicted Cluster assignment and predictive performance of the modeling algorithms was assessed by overall cluster assignment accuracy, Cohen’s inter-rater accuracy metric (high values indicate good accuracy) and Brier score (low values indicate good performance) in the training and test subsets of the study cohort. Performance metrics are presented in scatter plots. Point size codes for the overall cluster assignment accuracy. Point color codes for the modeling algorithm. Numbers of complete observations are displayed in the plot captions.*

*(B) Sensitivity (Se) and specificity (Sp) of detection of participants assigned to the PTS cluster (post-traumatic stress) investigated by receiver-operating characteristic in the training and test subset of the study cohort. Sensitivity and specificity values are indicted in the plots. Line color codes for the modeling algorithm. Numbers of complete observations and observations in the PTS cluster are indicated in the plot captions.*

*RF: random forest; NNet: neural network with a single hidden layer; SVM/radial: support vector machines with radial kernel; RPart: recursive partitioning; SDA: shrinkage discriminant analysis; cForest: conditional random forest; Elastic Net: elastic net multinomial regression.*

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