https://doi.org/10.2352/ISSN.2470-1173.2019.1.VDA-682

Correlation Visualisation for sleep data analytics in SWAPP (Sleep Wake Application)

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Abstract

Sleep plays an important role in the overall health and well-being of a child. The relationship between sleep and daytime behaviours of children with neurodevelopmental disorders is understood poorly; different aspects of a child's routine may interact with each other to contribute to sleep disorders. In order to diagnose, monitor and successfully treat many medical conditions pertaining to sleep, it becomes imperative to analyse the many aspects of a child's daytime and sleep behaviours. In this paper, we propose a visual analytic tool for studying the interaction of different variables collected for a child with neurodevelopmental disorders. We propose a visual analytic tool which allows clinicians to explore how the different aspects of a child's behaviour and activities affect their sleep. This tool is developed as an extension of an existing tool SWAPP, which allows caregivers and clinicians to log and monitor the child's everyday data.

Introduction

Sleep is an essential part of a child's health. Research shows that children in the age group 6-12 years should sleep 9-12 hours a day to promote optimal health [33]. Sleep disorders among children impede their proper "physical, cognitive, emotional and social development" [47]. Also, sleep disorders and sleep deprivation can lead to complications such as "obesity, diabetes and impaired glucose tolerance, cardiovascular disease and hypertension, anxiety symptoms, depressed mood and alcohol use" [7].

Up to 50% of the children in the society may have sleep-related disorders [9, 32, 26]. The common sleep disorders such as parasomnia (sleepwalking, confusional arousals, sleep terrors, nightmares), behavioural insomnia of childhood, delayed sleep phase disorder, restless legs syndrome all may be diagnosed from the analysis of the sleep history of the child [9]. Furthermore, obstructive sleep apnoea requires, sleep data with accuracy and depth as from techniques such as Polysomnography (PSG).

Several studies [14, 11, 27, 41] indicate that sleep disorders may be under-diagnosed in paediatrics. This may have a pejorative impact on the day to day life of those undiagnosed children, which is corroborated by previous medical research [18, 19, 36, 27]. Research shows that the majority of parents are unable to produce a faithful account of the insomnia episodes and sleep history to paediatricians [12, 41, 44], which would aid the diagnosis and treatment. Chervin et al. discovered that less than 15% of the children with parent-reported sleep disorder had no sleep history data pertaining to the same [15]. Wise et al. [47] substantiate this fact by stating that, "because parents are generally asleep during the night" they are unable to come up with a more polished record of the sleep data. Note that such studies involved paper-based logging methods, which is far less efficient than the health informatics solutions.

Kluwer [28] seems to implicate that the process of interpreting the sleep history itself is highly intellectually and analytically taxing for the medical practitioners, as the datasets involved are considerably large and their dependencies on the medical condition of the person may well be intricate.

To summarise, there is a considerable portion of the child population who are suffering from sleep-related disorders, which may lead to numerous health hazards. Sleep history plays a significant role in the diagnosis and treatment of sleep disorders. Parents face significant difficulty in logging such sleep history data. Finally, the doctors interpreting the results, have significant difficulty doing so. Our work SWAPP (Sleep Wake Application) is aimed at overcoming the shortcomings mentioned above. SWAPP is a web-based health informatics application that allows logging of sleep-related data of a child by the child's parent/caretaker, through the caretaker account on the application. This data is accessible to the clinicians via the clinician account linked to the child's data. SWAPP is also equipped with a clinician dashboard which provides the summary and other insights on the entered data and previous data assessments made. The dashboard exploits various visual analytic primitives to aid the doctors to better interpret the data.

Research has shown that sleep-related variables (many studies refer to them as sleep factors, e.g., sleep duration, sleep mood etc.) can be closely correlated to behaviour problems in "school-aged children" [45] or "preschoolers" [25]. Numerous studies have outlined the importance of analysing the various drug interactions with sleep-related behaviours/disorders [16, 29, 42]. Shrivastava et al. point out that analysis of sleep diaries/sleep logs is incessant for "referring physician to review the sleep study report and correlate patient's presenting sleep complaints to the results" [40] and also corroborates that multiple factors the sleep logs are involved in the analysis of the disorders, similar results are presented by other researchers [34, 10]. In order to cater to the data analysis needs of the clinicians, we would like to introduce a tool to explore the relationship between variables such as sleep duration, sleep quality, behaviours, medication, moods etc. We use correlation visualisations to support exploration of the relationship between variables, which is also the prime focus of this paper.

Related work

The review of literature began with exploring possible visualisations for representing the correlation. Our application aims to minimise the complexity of the visualisation and allow effortless interpretations. Past studies have shown that 3d plots are significantly more difficult to interpret than their 2d counterparts for large datasets [35], so we will be limiting our discussion to two-dimensional visualisations. The proposed interaction aims at al-

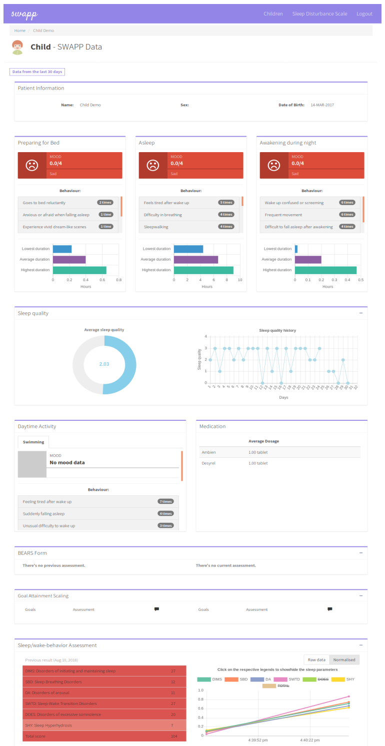

Figure 1. *Dashboard of SWAPP*

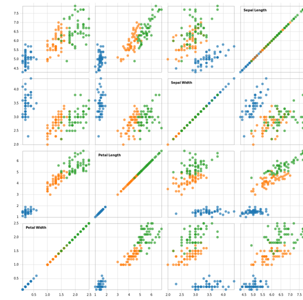

Figure 2. *A scatter plot matrix example of petals and sepals of a plant* [4]

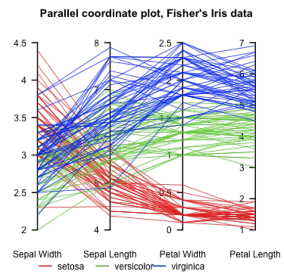

Figure 3. *A parallel coordinate plot example of petals and sepals of a plant* [2]

lowing users to exercise selective control over a subset of variables to be analysed for correlation from a larger pool /set of variables. In SWAPP, we log over 20 variables which makes it imperative that the chosen visualisation method is optimal for analysing correlations for numerous variables. The clinicians are assumed to have minimal knowledge of the statistical primitives involved in correlation/relationship analysis between the variables. If a user with significant exposure to the statistics and sufficient knowledge of the sleep data itself wants to apply the expertise into the analysis, provision should exist to provide the user with a comprehensive overview of the samples in the data, i.e, for the exploratory analysis of the data.

Numerous data visualisations have been applied in the pursuit of visualising correlations in the previous research literature, the most obvious one being the scatter plot [30]. Scatter plots are useful tools in interpreting the "direction, form and strength" of the relationship between two variables [30]. This may be extended to analysis for multivariate relationships by using scatter plot matrices [17]. Scatter plots offer the advantage that they can be easily be generated from raw data without any analytical computation, they provide insight on each and every sample point in the dataset. Interpreting the scatter plot may not be straightforward and may require very stringent analysis of the plots, especially with increasing number of dimensions/variables [43]. Thus, it is worthwhile to have a visualisation which requires minimal mental exertion for a user, also allowing the user to reject insignificant relationships at a glance. Some previous literature [21] also refer to parallel coordinate graphs for interpreting correlations. Despite being a powerful visualisation they tend to take a longer duration to interpret with increasing number of variables, moreover, they cause cluttering. More complex visual analytic solutions like contingency wheel [8] work best when there are myriads of variables/dimensions compared to what is required in SWAPP, interpretation of the contingency wheel also tend to be more complex than the techniques discussed above and expects some familiarity with the visualisation.

The alternative to using exploratory data analysis is to make use of Pearson's / Spearman's coefficient for correlation which leads us to the correlation matrix. This correlation matrix can then be conveniently visualised to infer correlations. Researchers have proposed multifarious methods which may be applied to visualising the correlation matrix. One such visualisation is parallel sets [24], which is a categorical version of the parallel coordinates which may be used to visualise quantifiable relation-

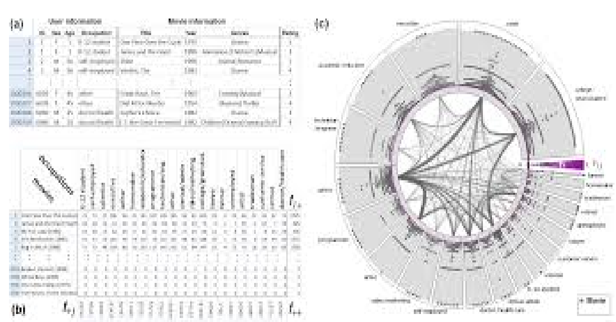

Figure 4. *Contingency wheel* [8]

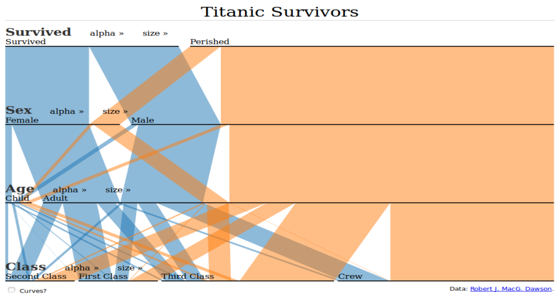

Figure 5. *Parallel set visualisation*
[3]

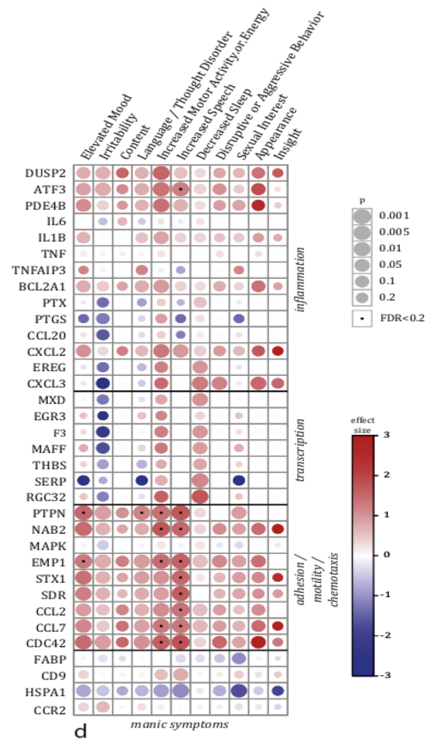

Figure 6. *A modified heatmap, showing effect size and significance*
[20]

ships between variables/categories, but as with the parallel coordinates, with an increasing number of variables, the interpretations from the visualisation may not be straightforward. Other conventional visualisations for depicting relationships, including Venn diagrams [23] do not work too well for larger dimensions /variables and quantifying the inferences tend to be cumbersome and erroneous in such cases as circle/ellipse intersections are difficult to interpret and compare. Connected graphs [39, 38] have also been employed in visualising, however as with the case of contingency wheel, such approaches work best for a very large number of variables. Variants of this method include, approaches such as clustering/ dendrograms successfully applied in multiple disciplines [37], such methods, unfortunately, assume a connected relationship or correlation between all the variables. Correspondence analysis [22, 46] and its modern variant- moon plots [13], showing close resemblance to scatter plots have been deployed successfully in correlation analysis in multiple disciplines traditionally, however, analysis revealed that there is some confusion introduced by the visualisation while a novice user interprets them [13], although moonplots attempt to rectify the shortcomings, the method does not prove to be foolproof. Other methods like solar correlation plots [48] are confusing when it comes to interpreting negative correlations, and have found very little application in the research domain. The heatmap of the correlation matrix is an option that comes closest to satisfying the primary requirements of the SWAPP correlation analysis tool, the technique has been successfully applied in correlation/relationship analysis/ display in multiple disciplines including health informatics [20] and could possibly be the most used visualisation in correlation applications. Unfortunately, even the heatmaps do not support exploratory data analysis, i.e, provide a comprehensive overview of the data samples, this is something that is addressed in the proposed system.

Proposed system

The idea of visualising correlations between variables of interest is not unique. Many statistical software products like SPSS [5] and JMP [1] allow users to find correlations between two variables. However, the use of such software assumes knowledge about statistical primitives and the software packages, which is often lacking for a practising clinician whose domain knowledge is usually disparate from the above. Moreover, given that the doctors work on a strict time schedule, investing time for such knowledge is rather taxing. Hence, in order to address such impediments in interpreting the sleep data variables for correlation, there is a need to accommodate a tool that requires minimal effort from the clinicians using it, while providing accurate interpretations of the data. Since the tool is integrated into the data acquisition or sleep logging system there is no need to clean up or format the data for correlation assessments. Furthermore, the procedure involved in generating the correlation reports from such statistical software packages tend to progress in a tedious and algorithmic manner, thus work-flow can be reused for a given set of data variables. Moreover, opting for a visual analytic solution as opposed to an intelligent agent that interprets the data gives the experienced clinicians more power, control and flexibility in the data interpretation.

The interaction

The design and layout of the interaction are inspired from the data visualisation software Tableau [6]. The available sleep-related variables/parameters/events for visualisation are stacked on the left-hand side of the visualisation in categorical boxes (figure 7 (a)). Note that the variables are in the form of the small rectangular capsules (figure 7 (b)) in the larger categorical boxes (figure 7 (a)). The categorical classifications of the sleep variables, i.e., headings of the boxes holding the sleep variables are designed to closely resemble the categorical classification and boxes that can be found on the clinician dashboard of the SWAPP web application, this ensures recognition of the variable setup from the dashboard which the users are already familiar with, rather than contrived recall of the setup, which is one of the key heuristics of interaction evaluation according to Nielsen [31].

There is a 'horizontal box'(figure 7 (d)) and a 'vertical box' (figure 7 (c)), to the right of the 'variable/parameter boxes' (figure 7 (a)). These horizontal and vertical boxes act as input for the x-axis and y-axis of the visualisation respectively. Initially when the page loads, the area where the visualisation originally appears is depicted by a white space to the right of the 'y-axis box' (figure 7 (c)) and above the 'x-axis box' (figure 7 (d)). The user can initialise the visualisation by dragging and dropping 'individual variables'(figure 7 (b)) into the 'x-axis box' and 'y-axis box'. There is a direct correspondence between the order of variables along the respective axes in the visualisation and the order of variables in axes boxes, the interaction allows reordering and even moving variables between the two axes boxes according to the user's needs by further dragging and dropping. The user can remove unwanted variables from the x-axis and y-axis boxes by clicking on the 'x' button (figure 7 (e)) on the right of the rectangle containing the variables.

The visualisation

As discussed in the related work section, all the existing methods were inadequate on their own to deliver to the requirements of the application of sleep data analytics, where the users are typically doctors. The alternative was to combine two of the visualisations cited in the previous research section, by exploiting the best features from 'two worlds' for the convenience of the user. Careful analysis of the possible combinations of the visualisations suggested that combining the heatmaps with the scatter plots satisfied the requirements of the application. The primary visualisation is a heatmap plot of the correlation matrix arising from the variables dropped in the x-axis and y-axis boxes. There should be at least one item in both x-axis box and y-axis box to initialise the visualisation. Pearson correlation coefficients are used between two continuous variables and Spearman's coefficient is used if a discrete variable is involved. As discussed above there will be columns in the visualisation corresponding to the variables dropped in the x-axis box and rows corresponding to the variables dropped in the y-axis box. The intersection of the rows and columns i.e, the individual cells in the visualisation depict the correlation between those two variables. The visualisation was designed using the Plotly, a JavaScript library. Colour is used to represent the value of the individual correlations or the effect size; a red-blue scale is used for mapping correlations (figure 7(f)). The red region on the scale represents a high positive correlation while the blue signifies a high negative correlation. The size/radius of the circle represents the significance value. We identified that the effect size is as important as the significance value/ correlation when it comes to assessing relationships between variables, in the light of a previous literary work[20]. The transparency of the circle in the heatmap was adjusted to represent the product of the magnitude of correlation and the difference of the significance value from unity.

Since the requirement of the system was to simplify the primary analysis of the sleep variables for correlation. Meticulous filtering from trials of the possible visualisation designs discussed in the related works section revealed that the heat map visualisations provide a quick overview when analysing numerous variables. The visualisation also proved to be the most intuitive and effortless for a novice user. Once, the user has figured out on the pair of variables that need to be examined, the user can gain further insights into the variable pair from the scatter plot between the two variables. This is achieved by clicking on the respective circles on heat map visualisation, which would then display the scatter plot between the two variables as a popover. This would allow the user to have a deeper view of the sample points in the data. Jittering was introduced in the scatter plot to accommodate visualisation of discrete variables using a scatter plot.

Conclusion and Discussion

The proposed system, including the visualisation and the interaction, provides a convenient platform for the clinicians in assessing the sleep-related data for the correlation between various sleep-related variables. Need for such a system that aids identification correlations between sleep variables was recognised both from existing scientific literature and informal discussions with the clinicians, who are the primary users of the system. The proposed system is closely integrated into the patient data acquisition web application- SWAPP, making it easier and faster for clinicians to use analyse the data.

The design of the visualisation achieved by a comparative review of the possible visualisation techniques presented in existing scientific literature. We evaluated the merits and demerits of each visualisation with respect to the requirements posed by the specific application of the tool and the users of the tool. Development of the proposed system was done by the assumption of a user model for the application; the user is presumed to be a practising clinician with minimal knowledge of statistics. The categorical arrangement of the variables is designed to be closely related to the original dashboard of the SWAPP web application. Drag and drop scheme for control of the visualised variables provide users with a convenient and intuitive method of manipulating the variables of interest.

The principle of operation of the interaction and the visualisation may be summarised as a two-step process:

1. A primary visualisation aims at fast, accurate filtering of the relevant variables based on their correlations, achieved by the heat map.
2. A secondary visualisation that allows exploratory data analysis of two variables of interest, by means of a scatter plot.

The heatmap provides the user with a quick summary of the variable correlations. The proposed system carefully integrates the use of significance and effect size parameters into the heatmap, as both were found to be relevant to the interpretation of data. Once the variables of interest have been identified, the user can initiate the scatter plot by clicking on the respective circles corresponding the set of variables. The scatter plot provides a powerful tool to gain a deep understanding of the relationship between the variables of the data for users with necessary data analytic skills, knowledge and experience.

While the integration of the proposed system into SWAPP web application is still a work in progress, and the figures illustrated are based on synthetic data, the final integration of the tool would closely resemble the design presented in this work. Future iterations of the research aim at interviews and surveys targeted at users (clinicians) of the proposed system in-situ scenario. This provides an opportunity to assess the system in the light of real data. The system will be assessed for speed, effectiveness and accuracy of the interpretations and conclusions posed.

Figure 7. *Annotated interaction for the visualisation*

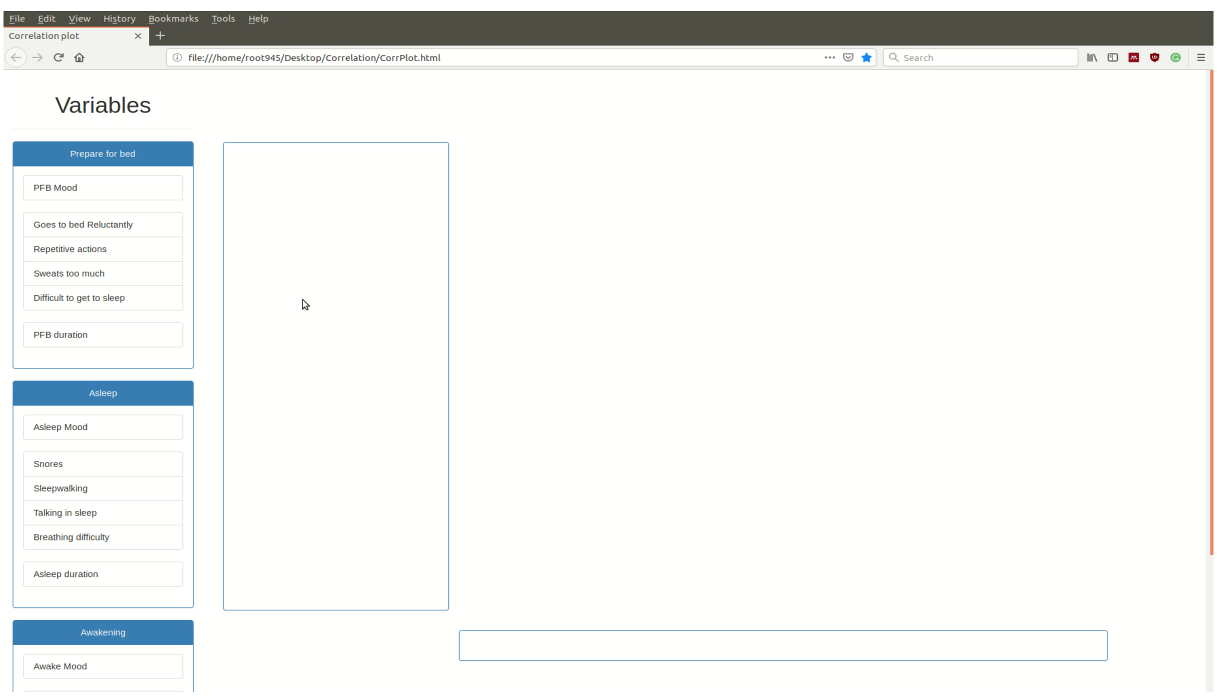

Figure 8. *Initial view when the correlation visualisation tool loads in the browser*

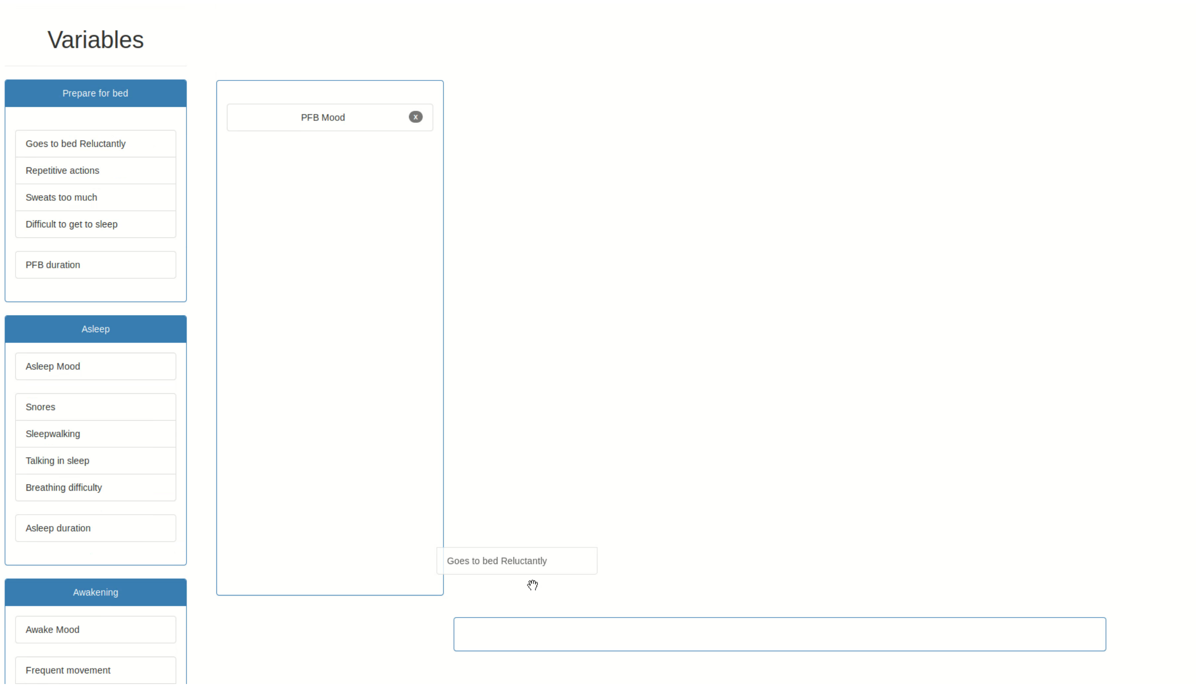

Figure 9. *Drag and drop items into the X-axis and Y-axis boxes to initialise the heatmap visualisation*

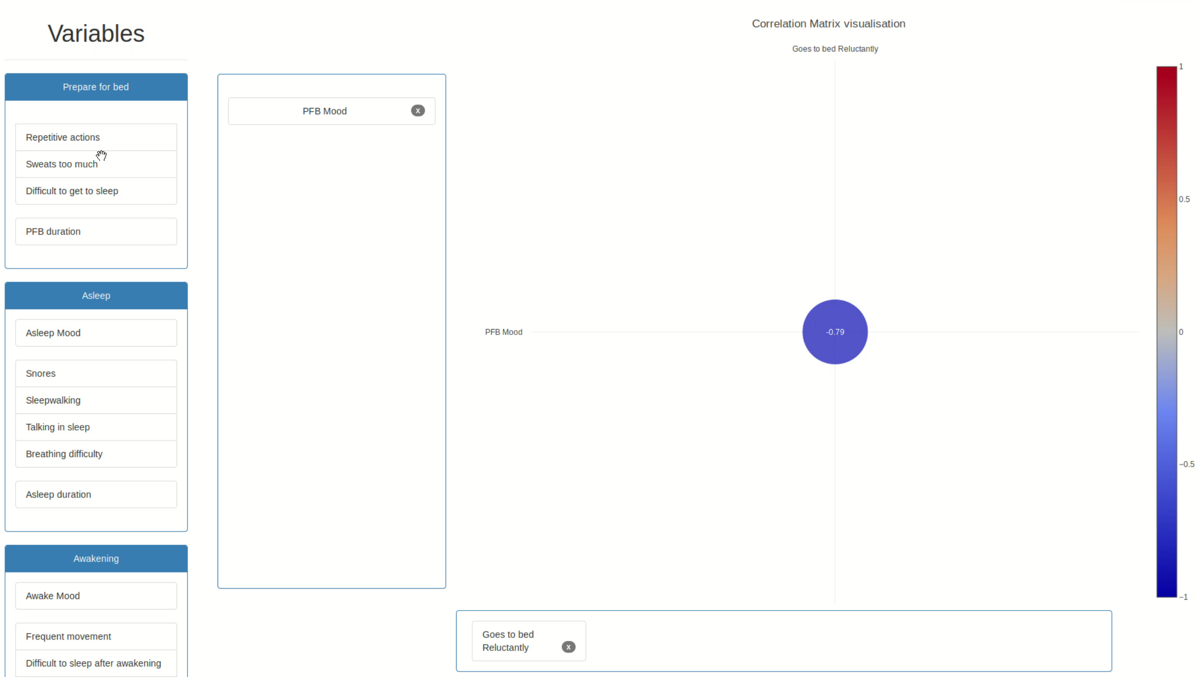

Figure 10. *View after drag and drop. The colour of the circle reveals the correlation between corresponding variables with regards to the heatmap scale, correlation value is also written in text on the circle (-0.79 in this case). The radius of the circle shows the significance of the correlation. Finally, the transparency of the circle is a combination of the significance and correlation (by multiplication).*

Figure 11. *One vs many search in the variable space using drag and drop reveals all the variables that correlate with the variable of interest (PFB Mood in this case).*

Figure 12. *Scatter plot integrated into the visualisation, revealed by clicking the circle in the heatmap, this example shows the scatterplot of two discrete variables with positive correlation*

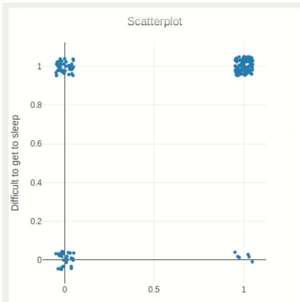

Figure 13. *Jittering was added to the scatterplot popover where discrete variables were involved*

We believe that the knowledge arising from our research may be applied to other data analysis problems both inside and outside health informatics while dealing with correlations. Validation of the above thesis also a potential future work.

Acknowledgements

Development work for this project was supported by NSERC (RGPIN/05739-2016). This study was funded by the Canadian Institutes of Health Research (CIHR) grants (funding reference numbers: CEH - 126527, and THC-134235).

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