DATA ANALYSIS OF AGE-RELATED CHANGES IN VISUAL MOTION PERCEPTION

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Keywords: Mixed ANOVA, Fuzzy clustering, Psychophysical experiments, Motion discrimination, Ageing, Visual perception, Individual, Gender and group differences.

Abstract: Many cognitive abilities decline with age, but ageing is accompanied by great variability within older population. The aim of the present study is to explore the possibility to differentiate the age-related and the individual differences in visual information processing. Two different analytical methods – mixed ANOVA and fuzzy clustering, were applied to the data of psychophysical experiments on motion direction discrimination. The results suggest that the complementary analysis based on both methods offers new opportunities to retrieve information from the psychophysical studies and to separate the differences due to age and gender from the individual differences of the participants. The proposed data analytic approach allows better understanding of the factors that caused variation in performance with age and can be used as a diagnostic tool to distinguish pathological from normal ageing.

1 INTRODUCTION

Ageing depends on a multitude of factors - biological, genetic, social, economic, etc. The most wide-spread approach in studying cognitive ageing is to compare the performance of the participants from two age groups (e.g. Habak & Faubert, 2000; Raz, 2004; Govenlock et al., 2009; Berard et al., 2009; Pilz, Bennett & Sekuler, 2010; Allen et al., 2010) or to find a correlation between different behavioural measures and age (e.g. Billino et al., 2008). While these analyses provide valuable information about the factors that affect the age-related changes in the cognitive processes, the individual differences among the subjects are greatly undermined or are examined mainly through a correlation analysis (e.g. Rose et al., 2010; Busey et al., 2010). However, the variability among the participants might include different life experiences, genetic influences, preferred strategies and susceptibility to neuropathology (e.g. Hedden & Gabrielli, 2004). For this reason it is important to evaluate the individual differences in order to determine behavioral norms and to distinguish normal from pathological ageing. The psychophysical studies have the potential not only to describe human performance but also, when combined with other data, to be used as an indicator for degenerative processes.

The aim of the present study is twofold: First, to suggest new data analytic strategies for individual differences between the participants in psychophysical experiments; second, to determine the most appropriate conditions for evaluation of these differences. In order to achieve this goal we selected four experiments from our dataset of studies on visual perception of dynamic information. The experiments focus on the age-related changes in the sensitivity to motion direction of dynamic noisy stimuli. Here we will concentrate only on the evaluation of the different analytical techniques and experimental conditions that will provide better segmentation of the age-related changes from the individual characteristics of the participants.

Bocheva N., Georgieva O. and Stefanova M..
DATA ANALYSIS OF AGE-RELATED CHANGES IN VISUAL MOTION PERCEPTION.
DOI: 10.5220/0003147505560561
In *Proceedings of the 3rd International Conference on Agents and Artificial Intelligence* (ICAART-2011), pages 556-561
ISBN: 978-989-8425-40-9

2 METHODS

2.1 Subjects

Twelve younger subjects (mean age 19.5 yrs., range 16-24 yrs., six male) and 12 older subjects (mean age 73.9 yrs., range 66-82 yrs, four male) participated in the experiments. All of them have normal or corrected to normal vision.

2.2 Stimuli

The stimuli consisted of 50 frame movie sequences showing spatially band-pass elements. They moved in circular aperture with radius of 7.0 deg, positioned at the middle of the computer screen.

In Experiments 1 and 3 the moving elements were 32, whereas in Experiments 2 and 4 they were 128. If any element left the aperture during its motion, it re-appeared from the opposite side of the aperture in order to keep the number constant. The mean speed of motion in all experiments was 6.64 deg/s. In Experiments 3 and 4 the speed of the individual elements deviated from the mean speed to a by a random amount determined from a normal distribution with spread of 1.32 deg/s. The motion direction of each element was taken randomly from a normal distribution of different spread. Six different values of the spread were used: 2°, 5°, 10°, 15°, 25°, and 35°. They determined the level of external directional noise.

2.3 Procedure

The task of the observers was to indicate whether the mean direction of motion appeared to the left or to the right of the vertical. In all experiments the average direction of motion was downwards. After each trial, an adaptive algorithm estimated the angular deviation of the mean direction from the vertical to be presented on the next trial.

Each subject participated in four experiments. The experiments were divided in 3 blocks: a training session of 60 trials and two experimental that involved six separate adaptive QUEST (Watson & Pelli, 1983) staircases of 40 trials for each noise level. The subject sat at a distance of 114 cm from the computer screen. The observation was binocular.

2.4 Statistical Analyses

A non-parametric bootstrap procedure was applied to the responses of each subject and experimental condition to find a maximum-likelihood estimate of the discrimination thresholds (tm) at which 82% correct responses were obtained. A Weibull function was used as a psychometric function model.

A between-within subjects ANOVA (mixed ANOVA) with factors: age, gender and noise level was applied to the log transformed thresholds obtained in each experiment. A multivariate approach (Rencher, 1995) was used to the within-subject tests. A post-hoc Tukey HSD test was applied to the results of ANOVA with factors: noise and subjects to divide the participants in homogeneous groups.

2.5 Clustering Algorithm

A fuzzy clustering technique that finds not well separated data groups with vague and uncertain boundaries was used. The clusters are described by their centre. In the simplest case, this is a point in the data space that is most representative for the cluster in probabilistic sense. Every point of the data space belongs to the distinct clusters with different degree of membership – a value between 0 and 1, such that if the data is close to the cluster centre, the membership degree is closer to 1.

The widespread *Fuzzy-C-Means* (FCM) algorithm (Bezdek, 1981) was applied. It is an objective function-based algorithm with clustering criteria defined as:

$$J = \sum_{i=1}^{c}\sum_{k=1}^{N} u_{ik}^{m} d_{ik}^{2}\ , \tag{1}$$

where N is the number of data points; c is the number of clusters; u_{ik} and d_{ik} denote correspondingly the membership degree and the Euclidean distance of the data point x_k, k=1,...,N, to the i-th cluster centre, i=1,...,c. The coefficient $m \in [1,\infty)$ determines how much clusters may overlap. Usually m=2 is taken.

As the number of data N=24 is relatively small, meaningful partition could be expected for clustering in no more than two or three clusters. The appropriate c could be accessed through the cluster validity measures that estimate the goodness of the obtained partition (Babuska, 1998):

a) Average within-cluster distance (AWCD)

$$\mathrm{AWCD} = \frac{1}{c}\sum_{i=1}^{c}\frac{\sum_{k=1}^{N} u_{ik}^{m} d_{ik}^{2}}{\sum_{k=1}^{N} u_{ik}^{m}}\ , \tag{2}$$

monotonically decreases with the number of clusters.

b) Fuzzy hypervolume (Vh)

$$\mathrm{Vh} = \sum_{i=1}^{c} [\det(F_i)]^{1/2} , \tag{3}$$

where $\boldsymbol{F}_i$ is a fuzzy covariance matrix of i-th cluster. Good partitions are indicated by small values of Vh.

3 RESULTS AND DISCUSSION

3.1 Age and Gender Effects

In all experiments the mixed ANOVA results show significant effect of age (F(1,20)=8.67; 6.60; 7.01 and 18.59 for Experiments 1-4, p<0.05) due to the higher discrimination thresholds and thus, to the lower sensitivity to motion direction, of the older subjects. The gender has insignificant effect at p=0.05 (F(1,20)=0.17; 2.58; 1.56 and 0.72 for Experiments 1-4). The interaction between age and gender was significant only in Experiment 2 (F(1,20)=4.91; p<0.05) due to the differences between the male subjects from the two age groups. The noise level had significant effect on the performance; the thresholds increased with the increase in the noise levels (F(5,16) = 13.37; 11.47; 19.66 and 15.66 for Experiments 1-4; p<0.05). No significant interaction is observed between the noise and either age or gender. The triple interaction was also insignificant at p=0.05. Figure 1 illustrates the effect of the noise level on the mean thresholds in each experiment.

An additional ANOVA was performed with age and gender as between-group factors and dot number, the speed variability (present or absent) and the noise level as within-group factors. The results show again a significant and independent of the noise level effect of the age (F(1,20)=13.50; p<0.05). The speed variability affects the sensitivity to motion direction – when the speed of the individual elements is different, the performance improves (F(1,20)=4.55; p<0.05). This effect is more profound for the denser displays as indicated by the significant interaction between the dot density and the speed variability (F(1,20)=6.62; p<0.05). The interaction between the noise level and the speed variability is also significant (F(5,16)=4.99;p<0.05). This result might be an indication for noise exclusion for a variable speed (e.g. Lu & Dosher, 2009) due to a better match of the spatial characteristics of the band-limited elements to the optimal motion sensitive mechanisms in the visual system.

To summarize, the results from the experiments show that the sensitivity to differences in motion direction declines with age. The lack of interaction between the noise level and the age group indicates that the age-related changes in performance are due to an increase in the multiplicative noise in the visual system i.e. the noise that depends on the strength of the signal (e.g. Lu & Dosher, 2009). The results suggest little effect of the gender on the sensitivity to motion direction, implying that based on their sensitivity to motion direction, the subjects could be divided in two groups determined by their age. The data do not allow distinguishing which experimental conditions are best for evaluating the changes in the performance due to either age or gender.

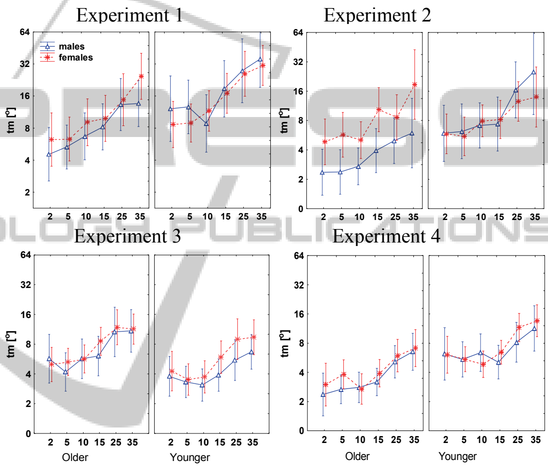

Figure 1: Effect of the noise level (on the abscissa) on tm. The error-bars represent one standard error.

In the mixed ANOVA each subject serves as his/hers own control and the analysis permits evaluating the contribution of the experimental factors on the performance and the common trend of the effects for the experimental groups. However, in order to implement this analysis, we need to ensure equal variance of the experimental groups and therefore, independence of the variance on the size of the noise level. In the cluster analysis such restrictions are not obligatory and we seek for groups based on the performance of the subjects using the untransformed data (i.e. without the logarithmic transformation of the thresholds).

First, the two-dimensional space determined by the age and the individual discrimination threshold tm for a particular noise level has been investigated. The FCM clustering provides the trivial partition in two clusters – the clusters of younger and of older subjects. The cluster centres are not sensitive to the noise level added to the stimuli and the clusters' coordinates are at about 19.5 years and 73.5 years.

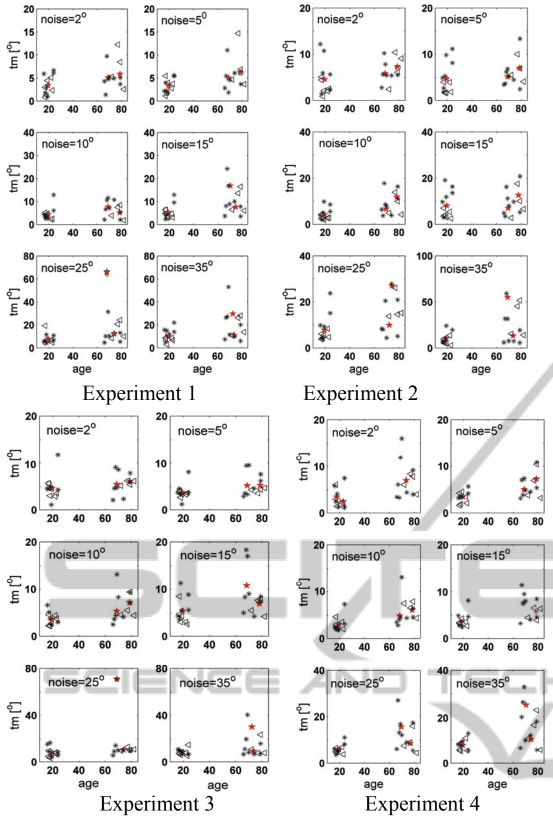

Figure 2: Clustering results for c=3. Red: cluster centre; triangles – males; asterisks – females.

The diversity within the trivial groups could be investigated by partition in three clusters. In this case the clustering is not stable as it provides more than one (local) minimum solution. Clustering, that finds minima of the criteria (1), for different initial partitioning was accepted. Additional assessment of the clustering quality according to the performance indexes (2) and (3) was done.

Except in Experiment 1 at noise level of 15º and 35º, the AWCD and Vh indexes decrease for c=3. This means that the partitioning in three clusters is more informative as the clusters are more compact and well defined. The common tendency observed is the splitting the older group (Figure 2). This corresponds to the complexity of the ageing process and it dependence on multitude of factors that leads to larger individual differences at older age. However, this fact is not equally expressed and depends on the spatial and motion stimulus parameters. Noise level of 15º for all data sets provides unstable clustering for c=3 for different initial partitioning.

How could we explain the differences between these two analytical techniques? In the ANOVA we have assumed that not only the age, but also the gender of the subjects affects the performance and we have compared the sensitivity to motion direction of 4 groups defined by age and gender. In the clustering, the grouping is determined by the age of the subjects and their performance. The splitting of the older group in two clusters does not necessarily imply that this is due to the gender of the subjects. Therefore, using two different methods of analysis we have obtained complementary data about the age-related effects in motion direction discrimination.

3.2 Characterization of the Individual Differences

To evaluate the individual differences in task performance ANOVA with factors: noise and subject (regarded as a random factor), was applied for each experiment. We wanted to evaluate how stable is the performance in the different experiments and whether data from one experimental condition could predict the performance if the conditions are changed. For this purpose, a post-hoc Tukey HSD test was applied and the subjects were divided in homogeneous groups based on their sensitivity to motion direction. The correlation coefficients between the ordering of the subjects based on their performance in the four experiments suggest that among the 6 comparisons significant correlation is obtained only between the orderings in Experiments 1 and 4 (correlation coefficient =0.62; $p<0.05$). The homogenous groups include subjects of different age and gender

The results of the analysis are presented in a graphic form in Figure 3. Each column corresponds to a different subject and each colour represents a different homogeneous group. It is clear that no distinct groups are formed between the different age groups. The possibility to describe the individual differences between the subjects by applying post-hoc tests is limited due to the fact that in these analyses we could not ensure equality of the variance of the individual data by any transformation. The measurements for each subject are few, and therefore, the violation of the ANOVA assumptions will have greater impact. Also, in the test we have disregarded the potential interaction between the subjects and the noise level. We have no good measure to affiliate each subject to a group. In this study only 24 subjects took part in the experiments and the minimal number of homogeneous groups that obtained by the post-hoc Tukey HSD test is six. If more subjects participated, the grouping based on their performance may become more complicated due to the undetermined separation between the groups and their large number. For this reason, we have applied cluster analysis to the data.

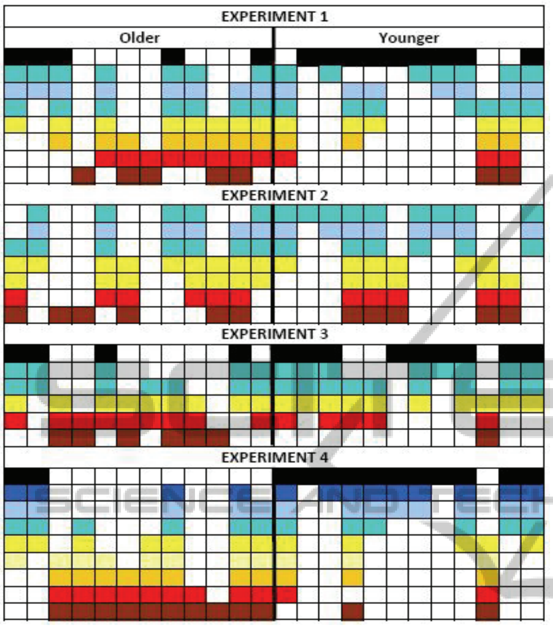

Figure 3: Representation of the homogeneous groups defined by the post-hoc Tukey test. The first 12 columns correspond to the older group, the second 12 – to the younger one.

Information about the individual characteristics of the subjects is searched by clustering in a higher dimensional data space, defined by the noise level values, independently of the subjects' age and gender. The division in three clusters is of a particular interest as the participants are divided in a group of high sensitivity (*H*) that corresponds to low thresholds values, a group of medium (*Md*) sensitivity and a low sensitivity group (*L*) that corresponds to high thresholds values. The results show that:

a) The cluster *H* of the low tm values contains mainly younger people and a few older ones;

b) The medium cluster *Md* associates female and male older subjects and few young females;

c) The cluster *L* is formed predominantly by the older females.

The obtained fuzzy partition matrix assesses the individual performance of a given subject to the whole space partition. The level of association of a person to every cluster is presented in Figure 4. It could be seen that cluster *H* is more compact than the others, which suggests small variation in the sensitivity to motion direction of the members of this cluster. As the others two groups predominantly associate older people, this again confirms the higher variability of the older group in comparison with the younger one.

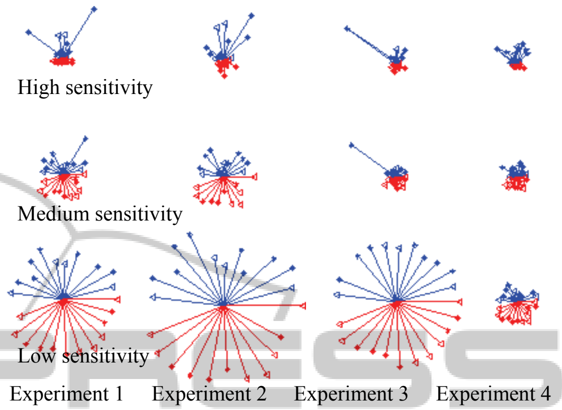

Figure 4: The distance of the individual discrimination thresholds from the cluster centres. Each point represents the data of a single subject. The order of the subjects in each plot is the same. Triangles – male; asterisks – female; blue – older participants; red – younger participants.

The general observation is that the clusters overlap more for small noise levels as well as for Experiments 1 and 2, whereas they are more distinguishable for large levels of external noise. When the external noise is low, the performance of the subjects is limited mainly by the internal noise in the visual system. At higher levels of external noise the contribution of the internal noise decreases and the performance is limited by the ability of the visual system to "resist" to the external noise, for example, by integrating the local motion information. The clustering data suggest that the level of external noise has little effect on the performance for the participants in the high sensitivity group.

The cluster of the high thresholds depends strongly on the external noise. In most experimental conditions, except in Experiment 4, single subjects belong to it, suggesting that they significantly deviate in their performance from the rest of the subjects. Experiment 4 allows the most distinct separation of the subjects in different groups based on their sensitivity to motion direction. It provides the opportunity to classify reliably new subjects to the existing groups and to treat the grouping as a norm for characterizing people. The motion displays in Experiment 4 contain a large number of moving elements with varying speed where the different realizations of the random samples might correspond more closely to the characteristics of the distributions associated with the noise level and the speed of motion. In addition, the variable speed may ensure optimal stimulation of the units in the brain, sensitive to motion direction.

4 CONCLUSIONS

The common analytical approaches used to portray the age-related changes in the different cognitive processes provide a good description of the trends associated with ageing and the experimental conditions when differences occur. This makes them a useful tool to characterize the process of ageing and to seek association between the behavioural data and the physiological changes in the brain. However, these methods are less efficient when the individual differences in the ageing process need to be evaluated.

Our study is a first attempt to apply clustering algorithms to differentiate the effects of age, gender and individual differences on performance of a behavioural task. The interpretation of the clustering results allows detecting the deviation level of a subject from the respective age group. Whether this is related to degenerative processes or not, could not be determined only by the results of the present study; it requires tracking the changes in the cognitive abilities of the participants in longitudinal studies. However, our data analytic technique provides opportunities to use psychophysical methods for early diagnostics of the deterioration in the cognitive abilities of the individual with age. The results of the cluster analysis suggest also, that it is easier to detect the individual deviations in demanding tasks and difficult experimental conditions.

ACKNOWLEDGEMENTS

This work was supported by grant TK01-200 of the National Science Fund, Bulgaria.

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