Eötvös Loránd University
Faculty of Education and Psychology
MA Clinical and Health Specialisation

THESIS

The Yerkes Dodson Law in Contemporary Academia: The quadratic relationship between emotional arousal and performance among university students

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2019

EÖTVÖS LORÁND TUDOMÁNYEGYETEM

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CONFIRMATION OF THESIS CONSULTATION

(a part of the thesis after filled out.)

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Student's programme: Clinical and Health Psychology Specialisation, MA

The thesis's topic: Relationship between emotional arousal and academic performance

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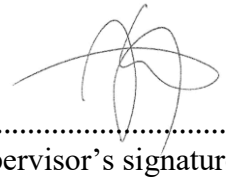
Time of consultation	Topic of the consultation, notes, suggestions	Supervisor's signature
2018-06-06	1) Introductions 2) Status of the project 3) Topics of interest in the project 4) Proposing to use a project management tool (Asana/Slack) 5) Operative tasks:	
2019-02-04	1) Collection processing data 2)Uploading Thesis to OSF 3)Approach to hypothesis 4)Student grading 5) First Deadline 6) R-studio 7) Structure and methods	
2019-02-22	1) Feedback on introduction and Methods 2) Deadline/ How to proceed	
2019-04-03	1) R-script coding 2) Interpretation of data 3) Feedback 4) deadline/how to proceed	

I allow the sumbission of the thesis.

Budapest, 2019.04.23.....



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supervisor's signature

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Summary

The Yerkes-Dodson law (YDL) states that optimal functioning can be achieved when an optimal level of arousal is maintained, and under and overexcitement can lead to poor performance. The YDL is one of few phenomena in psychology that has acquired the status of law throughout the centuries. However, there is surprisingly little evidence supporting YDL that exceeds animal studies and with more modern scientific methods. The present study investigates if the predicted quadratic – an inverted-U – relationship can be found between arousal and performance in an academic setting. We measured self-reported arousal, and the intensity of twenty discrete emotions in 769 university students right before university exams. Moreover, we acquired the grades of 501 of the participants that we used as a measure of performance. The Cumulative Link Mixed Models were used to investigate the effect of arousal on performance. We found partial supportive results. The self-reported arousal was best explained with the linear model to predict academic performance (OR 1.300 CI 1.117 – 1.512, p=.001), while we did not find significant results concerning the quadratic model (OR 0.941 CI 0.836 – 1.060, p=.317). On the other hand, the model containing arousal as emotional intensity (the sum of all emotional responses) showed a significant quadratic relationship to exam performance (OR 1 CI 0.998 – 1.000 p=.026). Using this predictor made the model better than the ones that included the linear effect of arousal.

Abbreviations

Adrenocorticotropin	ACTH
Central Nervous System	CNS
Cumulative Link Model	CLM
Cumulative Link Mixed Model	CLMM
Geneva Emotion Wheel	GEM
Salivary Alpha Amylase	sAA
Sympathetic Nervous System	SNS
Yerkes–Dodson law	YDL

1.0 Introduction

1.1 The Yerkes-Dodson law, now and then

It's been over one hundred years since the original study that inspired the Yerkes–Dodson law (YDL) took place, originally explaining the relationship between stimulus strength and learning behaviour it is safe to say the law has seen some change (1908). The relationship between arousal and performance known as the YDL today is commonly recognizable as the shape of a normal distribution curve, and is depicted in approximately one in tree introductory psychology textbooks (Winton, 1987). The curve explains, depending on the task, that emotional arousal is a positive influence on performance, until a point where the curve decrees, or the arousal overwhelms and compromise the performance (Passer & Smith, 2009).

It would, most probably, never have occurred Yerkes or Dodson, that their names would one day be used to explain taste-aversion in starving snails, this exemplifying vide variation in which the law is used today (Ito, Totani, & Oike, 2017). The experiment that gave the name was performed in the periodic style electric shock on laboratory "dancing" mice, originally intended to measure effective habit formation when exposed to unwanted stimuli. When Yerkes and Dodson found that moderate shock created habits/learned behaviour faster than mild, they expected a linear response between learning and stimuli strength, or the stronger the electric shock the faster the problem-solving skill is learned. They found that the intermediate electrocuted mice proved more successful in learning the task than the mice exposed to weak shock, but also strong shock. Puzzled by this, they reproduced the study by lowering the difficulty of the task and expanded the variability of shock strength from 3 to 5. As predicted the lower difficulty proved to confirm the linear hypothesis, the stronger the stimuli, the faster the problem-solving habit were learned. These opposing results gave them the idea to investigate the one changed variable, the difficulty of the task, and replicated the study a final time concluding that the optimal stimuli-exposing or optimal punishment, varied upon the nature of the task (Dodson & Yerkes, 1908).

The experimentation continued throughout the century with a wide variety of researchers and electrified creatures, from mice, rats, chickens, cats to humans, all in which had a tendency to rapport some inverted-U relationship, but it wasn't until later that the curve was established as "law" (Broadhurst, 1957; Brown, 2011; Dodson, 1915; Dodson & Yerkes, 1908).

1.2 Criticism: The creation of law

The loose scientific framework and definitions around the time of the original study can be a reason for the theory to blossoming into the law often utilized in vague inverted U-relationships. The fact that several of the earlier mentioned animal-studies early 20th century does not refer to Yerkes or Dodson but rather use their own terminology to explain their curve. The unitary YDL model of emotional arousal most known today can be traced, more or less, to Donald Hebb mid-century, and even this paper has no reference to either Yerkes or Dodson (Hebb, 1955; Teigen, 1994). All this inverted-U research were more or less tied together around when Broadhurst repeated the original study hypothesizing for emotionality, with more complex scientific methods, and found the inverted U-curve when waterboarding a more solid sample of rats (1957). Together with the arousal concept of Hebb and the contributing interest, one among them the psychological-celebrity Hans Eysenck, the YDL were quick to catch on with the scientific community (Hebb, 1955; Teigen, 1994). Growing out of this overlapping melting-pot of definitions some argue that the law is based on definitions too vague to be disproven scientifically and add up to an immortal and inaccurate law (Bäumler, 1994; Brown, 2011; Corbett, 2015; Neiss, 1988). In his review, Teigen exemplified this by gathering some of the different dependent and independent variables used by various authors throughout the last century that used YDL as an explanation. As seen in table 1. it gives an example of the unspecific frame the YDL has had throughout the century.

Table 1. Overview of concepts

Independent variables		Dependent variable
Stimulus strength	Discrimination difficulty	Habit-formation
Degree of punishment	**Task difficulty**	**Learning**
Intensity of motivation	Task complexity	**Proficiency**
Drive level	**Task novelty**	**Performance efficiency**
Magnitude of reward		**Quality of performance**
Level of arousal		**Efficiency of performance**
Emotionality		**Problem-solving**
Anxiety		**Efficiency of memory**
Tension		
Stress		

Note: Concepts used by various authors to describe the Yerkes-Dodson law. Almost all in the first column can be combined with almost any concept in the third column, with or without interaction with task variables (second column). Variables considered overlapping in current study is highlighted. Table used with authors permission (Teigen, 1994 p.541).

The fact that it was stated as "law" and remained so for almost a century is no lesser feat under the scrutiny of the academic and scientific community. The reason for its survival, some critiques argue, is only because its vague and undefined nature, that it is easy projecting existing subjective feelings around arousal to it, and that its almost satisfactory depicted in textbooks. (Bäumler, 1994; Brown, 2011; Corbett, 2015).

In addition to this the YDL is today used in explanation and justification of more unrelated fields, for example violence in police arrests, dosing and responds on medication, IT-developers capacity for multitasking, social facilitation in performing artists and of course, taste aversion in snails (Fox, Miley, & Moule, 2018; Ito et al., 2017; Teigen, 2019). The basis of YDL can be argued used in theories like Selyers' Eustress and destress, or Csikszentmihályis' concept of Flow and well-being (Csikszentmihalyi, 1997; Selye, 1976a). Also the YDL can be found overlapping with various modern tools like skill-training in therapy, meditation, relaxation techniques, music performance, workplace productivity and sport (Arent & Landers, 2003; Burnette, O'Boyle, VanEpps, Pollack, & Finkel, 2013; Chmiel & Schubert, 2017; de Manzano, Theorell, Harmat, & Ullén, 2010; Pekrun, Elliot, & Maier, 2006). Corbett goes so far as to warn that the loose law can be a harmful as it can be used to justify the creation and sustain distress in for example workplace environment (2015).

1.3 Problems with defining Emotion and Arousal

Blurred lines and overlapping definitions are however not a solved issue today, and even though the methods and complexity of definitions are significantly improved, there is in no way a universal agreement in the professional circuits. For example, the definition of emotion and arousal is still a well-known and debated matter. A study in 2010 tried to resolve this, to accomplish an agreement of definition by reaching out to 35 psychological scientists and behavioural neuroscientists gathering qualitative and longitudinal quantitative data. But with 35 participants they ended up with 34 different overlapping definitions of emotion, and the study concluded that emotions cannot be defined as a unitary concept. There were however agreement on the triggering factors of Emotional arousal suggesting in some levels the valid usage of a unidimensional explanation for Emotional arousal (Izard, 2010). An important question is if the unidimensional explanation of arousal is valid. Some arguments states that the human cognition, emotional and motivational factors are too complex to be explained in one single dimension, and if it cannot, the YDL loses its basis for explanation as natural law (Hanoch & Vitouch, 2004; Thayer, 1978).

1.4 Arousal

Arousal can as shown have many meanings, from Cannons' "Fight or Flight", to more modern definitions of activated central nervous system (CNS) are associated with most branches of psychology, like personality, behavioral, cognitive or positive psychology. There are two neurobiological systems that can be of importance in connection to the hypothesis. "SNS-adrenal-medullary arousal" is based in the sympathetic nervous system (SNS) and starting with the activation of the hypothalamus, an area that specialize in connecting the CNS to the endocrine system, in this case the adrenal medulla, the pituitary-adrenal glands whom produces adrenalin and noradrenalin. The "Pituitary-ad- renal-cortical" (HPA-axis) arousal, also considered starting in the hypothalamus, activate the pictuary glands, that release adrenocorticotropin (ACTH) that most importantly initiates the production of cortisol. All combined, when the individual is confronted with stressors is hit with a cocktail of adrenalin, noradrenalin, cortisol and dopamine dependent on the individual and situation. These chemicals are shown to have a positive effect in multiple situation, for example dopamine in the form of Ritalin for ADHD patients, ACTH is linked with memory function and adrenaline can also be helpful in situations where learned helplessness is present (Dienstbier, 1989; Pelham et al., 2004). Some theories cover the negative effects of these, arguing that too much

activation is generally considered bad for advanced cognitive processing. Among these, the "Fight, Flight, Freeze" – theory by Cannon also introduced in early 20th century, is today still being built upon. The theory can be summed up that human beings have a default evolutionary response towards arousal that would serve best against more primitive stressors, which were a more realistic danger in the greater part of human evolution. These responses, however, adaptive when encountering of a competing predator, would not be adaptive in cognitive demanding task like an exam; blood gathering in large muscle groups, getting ready to fight or to run, helped by adrenaline for explosiveness and cortisol and endorphins for expectation of pain (Bracha, 2004).

1.5 Emotional arousal

Emotions and arousal have a long time been linked to the point that they are almost synonymous. Walter Cannon himself recognized the closeness and together with Phillip Bard developed a theory on how the two interact, the theory goes that the emotional response is the initial response, and are continuously reinforced by the physiological signs of arousal(Fehr & Stern, 1970). This theory differs from for example the James-Lange theory that the physiological responses comes first which triggers an emotional reaction (Dagliesh, 2004). For this study there is however the only important factor is that they are linked and can fit the YDL.

1.6 YDL in recent Research

Considering the status of law there is mixed scientific evidence supporting the YDL, on the studies that exist there are contradicting findings regarding the modern interpretation of the YDL(Byron, Khazanchi, & Nazarian, 2010; Salehi, Cordero, & Sandi, 2010; Schilling et al., 2013; Westman & Eden, 1996). Where some argue the model as an oversimplified folk-law(Corbett, 2015), and others argue for the validity in numerous fields and schools(Byron et al., 2010; Easterbrook, 1959; Schilling et al., 2013). The issues of defining arousal as a single dimension is reflected in different outcome in all the specific and different situation where arousal was measured. For example a cross-sectional study were conducted on Israeli soldiers, where they found a significant negative linear regression between stress and performance (Westman & Eden, 1996), and another study found a positive linear relationship, testing recall

performance when measured skin conductance, or the tendency for skin to become momentarily better conductors when physically aroused, while playing video games (Jeong & Biocca, 2012). A laboratory study found a significant dose-responsive quadratic relationship with administered cortisol, or the stress-hormone, known to be produced and released in activation or arousal (Stalder et al., 2017). In 40 participants, where moderate levels of salivatory cortisol levels proved most effective in recall processes or scored highest in declarative memory tasks (Schilling et al., 2013). A meta-analysis on the effect of stressors and creativity also found support for the YDL, this with the analysis of 76 experimental studies (Byron et al., 2010). A similar selection as this study, a group of students had their level of alpha amylase (sAA), a measure of SNS activation, through saliva samples. Being told that arousal improves performance increased the level of sAA and significantly predicted a better grade, showing how individual problem solving is an important factor when confronted with stressors (Jamieson, Mendes, Blackstock, & Schmader, 2010). For a review of the positive effect of the positive aspects of an elevated SNS arousal on performance see Dienstbier (1989).

1.7 Research Plan

This study hypothesises that the YDL is valid in terms of academic performance. It will test this in two ways. We first hypothesis that subjective arousal will have a quadratic relationship with performance, or grades, in the form of an inverted-U. Multiple models will be considered, among them a linear for comparison. It is assumed that the quadratic model will be better to predict performance than the linear model. The second hypothesis is that subjective sum of emotional intensity has a quadratic relationship with performance or grades, multiple models will be compared.

This study takes the stand of arousal as a unidimensional conceptualization, where activation and deactivation are bipolar. Although it is acknowledged that some theories have a more complex and multidimensional approach to arousal and emotion, it can be argued that it does not necessary exclude a single macro dimensional activation theory, where this is the principle that the YDL is based upon (Corbett, 2015; Hanoch & Vitouch, 2004).. That arousal can be complex but still work as a unidimensional model is reflected in the second hypothesis,

this measures the intensity of 20 different emotions across four dimensions and pool it to one score. Because of the problems around definitions previously elaborated upon, this study measures subjective levels of arousal, thereby eliminating the problem of uncertain definitions by embracing the vagueness. Every participant may have a specific definition of arousal but as long as there exists a basic awareness of emotional introspection, the subjective approach to arousal is assumed to be valid.

This study has some similarities to the original study but uses a more modern scientific approach, reflecting the modern interpretation of the law rather than the original study. The participants are replaced from mice to humans, whom the modern YDL mainly apply, and a more representable sample of 769 rather than 5. The data processing and scientific methods have also seen considerable improvement. Rather than electrifying the students the subjective emotional arousal was administered through self-reported questionnaires, this excluding the necessity to manipulate any variables and considered an overall better solution. If the hypothesis is proven significant, it will provide lacking scientific support for a long-established law. Also, it strengthens the already established importance of skill-training for relaxation techniques/methods, and also motivational tools like goal setting in early schools (Burnette et al., 2013).

2.0 Method

2.1 Sample

769 university students were recruited from various subjects organized through Eötvös Loránd University in Budapest, Hungary. Of this collected data 546 of these were unique responses 135; 25% male, 408; 75% female, N.A. 3; 0.5%). Participants were either enrolled in a Hungarian (441, 81%) curriculum or an English (105, 19%), all a part of higher education and heterogeneous considering nationality and age above 18 years. Of these 546 unique responses, 501 participants gave permission to teachers to share their performance data.

All participants and teachers gave informed consent to take part in the study. Moreover, a permission for data processing was requested from participants to authorize teachers to share the exam grades with the researchers according to the data protection regulations of the University. The study protocol was approved by the ethical board of the Eötvös Loránd

University, and was conducted according to the Declaration of Helsinki, and with respect to the General Data Protection Regulation of the European Union.

2.2 Procedure

All courses were collected from the study register for the autumn semester of 2018/19 and were screened for inclusion in the study. Criteria for inclusion were form of testing: 1) either orally or in writing 2) conducted in a classroom, and 3) the exam had to be about the semesters' material i.e. no comprehensive exams. Professors associated with ELTE were approached by e-mail asking permission for data collection. Nine courses were included in the study, that together had 33 exams, the median of participants in each exam were 19 people (min. 4 max. 120).

We collected data from the participants right before and after exam with a short questionnaire. Before the data collection, participants were informed that the study was anonymous and voluntary. It was also stressed that the professor will not have access to the raw data or to connect individual answers to his or her students. Grades of the students who gave explicit permission for data handling were provided by the professors through an online platform that was developed for this purpose, based on the advice of the university data protection officer.

2.3 Measures

The participants received a two-parted self-report questionnaire, one to fill out before the exam, and one almost identical to fill out after the completion of the exam. The questionnaire was explained to the participants prior to the testing. If any confusion, the test-taker opened for questions, and the participants received a QR-code, or a link to the official OSF-site if they wanted any more information about the study.

Filling of the questionnaires required about 2 minutes each. We requested the Neptun code, gender, age, date, and the name of the course. A 5-point Likert scale was used to asses arousal "To what extent are you now in a heightened emotional state?", and the second measured subjective preparedness "How well do you feel yourself prepared for this exam?".

The Arousal factor were operationalized directly through the first Likert-scale, since the factor is supposed to measure subjective representation of emotional arousal, the question of validity should not be a problem, but ideally it would be better to have some more items for reliability. Earlier research have however used single-item Likert-scale for measurement of arousal and reported that it did not prove a significant issue for the study (Westman & Eden, 1996).

Included under these were the Geneva Emotion Wheel (GEW) that measures self-reported intensity of twenty emotions across four domains on a 5-point Likert skale (Scherer, 2005). Participants only had to mark emotions that they felt at the moment. The wheel is designed so that there are four emotional domains; negative to positive; and control, low to high.

Similarly, the second questionnaire after the exam measured arousal using the same 5-point Likert scale, and we also asked about the subjective performance in the exam "How well do you feel you have performed in the exam?", the Geneva Emotion Wheel was again included in the questionnaire. In this present study, we only used data from the questionnaire before the exam.

The measurement of performance among the students was asserted by the standard grading system carried out by the relevant teacher employed by ELTE-University. The grading used was a 5-point scale where 1 = fail and 5 = the highest possible mark. The question of what is measured in the dependent variable of exams vary. It is not a single factor like reaction-time or problem-solving but rather academic performance. This can contain a variety of measurement and cannot be considered a single variable. Rather, taking from the list depicted in Table.1, this study assumes that there are several overlapping variables. Among the list it can be argued that the exam tests proficiency (in the subject and test taking), performance efficiency (to distribute appropriate amount of time to the given problem and finishing the exam on time), quality of performance (grading system, especially in the essay responses), efficiency of coping (how well the individual coped with the stressful situation), problem-solving (especially in open ended questions or reflection tasks) and efficiency of memory (to produce the information on the curriculum, especially in multiple choice). Since these factors

vary among the subject-exams the difference among the courses is taken in consideration. The self-reported preparation is included as confounder to use in the discussion part.

2.4 Data processing and analysis

The data was processed and analyzed using the R programming environment (RTeam, 2018). We used ordinal regression using cumulative link models (CLM) with the R Package ordinal (Christensen, 2015). The CLM were used because the dependent variable was ordinal (1-5) thus requiring a more adequate regression analysis than for example a linear regression. The CLM fits and assess the observations as ordinal and test for proportional odds and scale effect. As we collected data from different classes, we had to account for the nested structure of error variances, therefore we used cumulative link mixed models (CLMM). The CLMM uses a Laplace approximation to create an estimate and maximum likelihood of the model class.

Regression models were created using the grade as the outcome variable and subjective arousal as the predictor. All models included the subjective preparedness as a confounder. Arousal was centralized using the grand mean of all students. We compared models that did not consider the common variance of classes with CLM (Model 1, and others that accounted the nested structure (CLMMs), where we used a random intercept model with the course as the grouping factor. The CLMMs used the linear effect of arousal (Model 2), the second the quadratic effect of arousal (Model 3), and the third with the interaction of subjective preparation(Model 4).

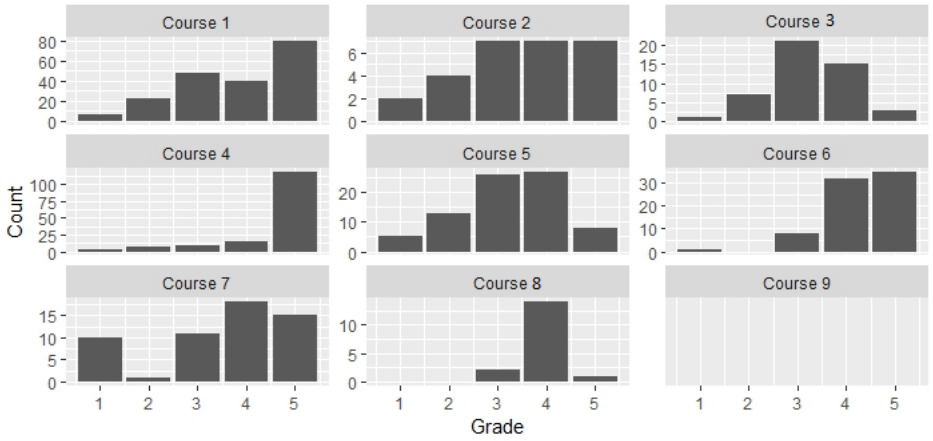
Log likelihoods were compared using chi-square tests, moreover AIC and BIC values were considered to estimate the superiority of models. Cox & Snell's and Nagelkerke's R2 was calculated for the residuals. The same procedure was repeated where instead of arousal, we used the sum of emotional intensity of twenty distinct emotions of the GEW as predictor. It is important to note that 87 participants may have misread the instructions and marked the intensity of all 20 emotions as 1 instead of just the ones that they experienced in the situation. We excluded these responses to avoid biased results. The sum of emotional intensity was also centralized using the grand mean.

3.0 Results

3.1 Distribution of grades

Visual inspection of histograms showed that the grades had a non-normal distribution in several courses . After inspecting each course there is some skewed distribution, where course 4 is most striking, where almost all students received top marks (5), more than six times more than the second-best grade (4).

Figure 1. Histogram Showing distribution of grades



Note: the y-axis is depicted independent for every course

3.2 Arousal

As seen in Figure 2. there is a decant normal distribution of arousal. In Table … the different courses are again depicted separately with the gray indicating the standard error of the mean (SEM) which is curvilinear (blue line). There seems to be a difference in distribution for the subjects, some show a positive relationship with little SEM (Course 1; Course 4; Course 6). Other have a larger SEM in low and high level of Arousal (Course 3; Course 5; Course 7). Course 2 seems to have a striking quadratic relationship. The

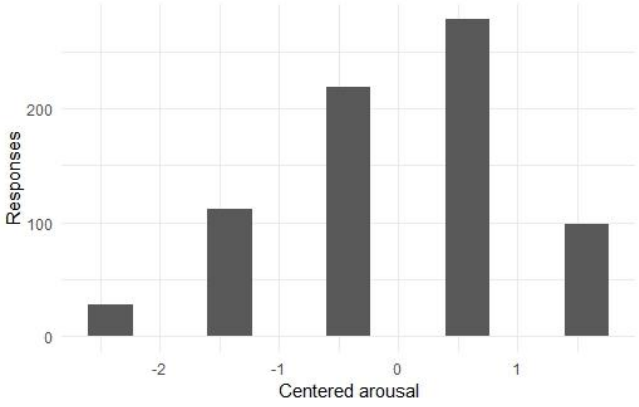
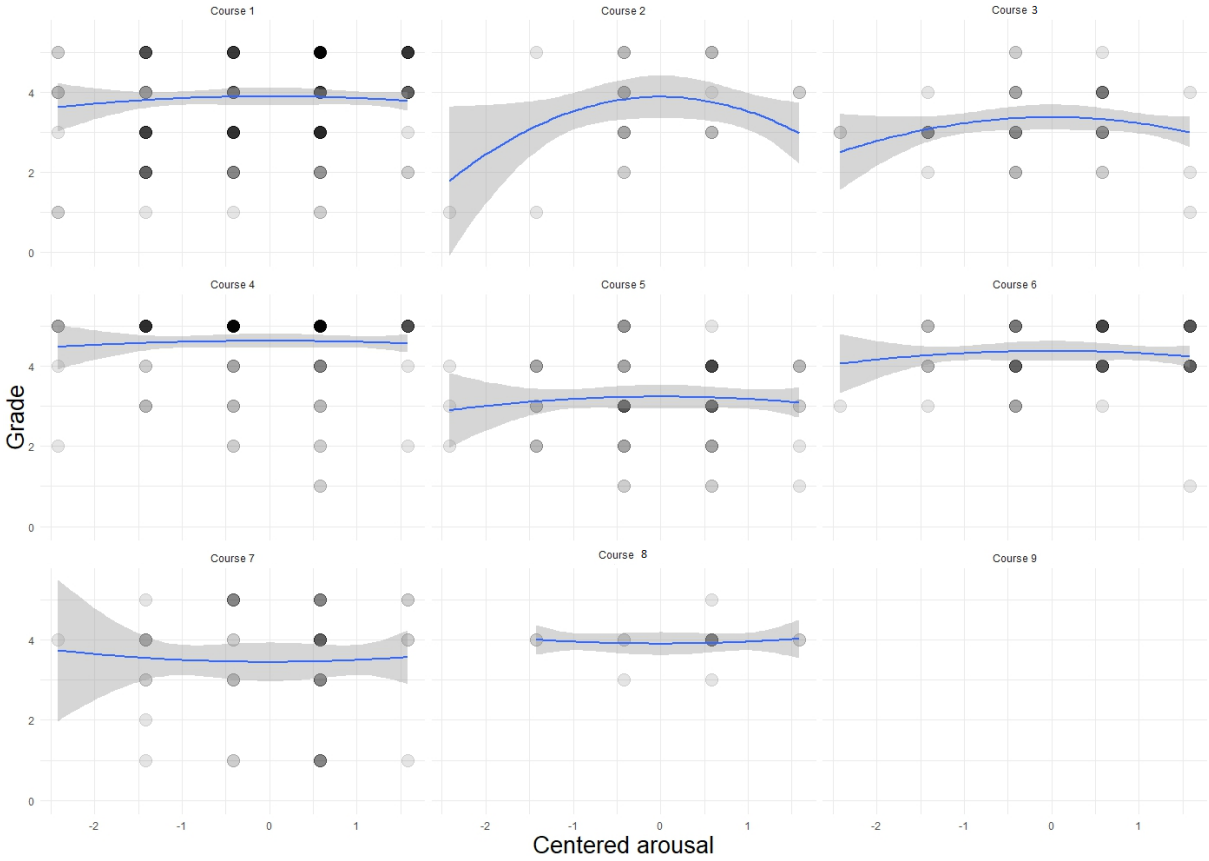


Figure 2. Distribution of arousal

superiority of the line also indicates the normal distribution of grades.

Figure 3 Arousal and grade



Different courses depicting centered arousal and grade. The blue line is a quadratic mean and the gray is the standar error from the mean.

Four models were built from the Arousal variable. Model 1 is a linear and CLMM, the model does account for the nested structure of error variances. The model proved significant with a OR of 1.30 CI 1.117 – 1.512 (p.001). The confounder model of subjective preparation gave a significant OR of 1.44 CI 1.224 – 1.698 (p<.001). Model 2 is a quadratic nested CLMM but with a non-significant OR of 0.94 CI 0.836 – 1.060 (p =.317). Model 3 used a non-nested CLM and yielded a non-significant odds ratio (OR) 0.95 Confidence Interval (CI) 0.849 – 1.064 (p>.377). Model 4 checking the interaction of arousal and subjective performance gave a significant OR 0.81 CI 0.682 – 0.956 (p=.013). Model 4 had a significant interaction with both Model 1 OR 2.499 CI 1.458 – 4.281 (p<.001) and the subjective preparation OR 1.537

CI 1.288 – 1.834 (p<.001). The AIC, BIC and logLik values also showed the linear model 1 as the best model as seen in table 2.

Table 2 Arousal model-comparison

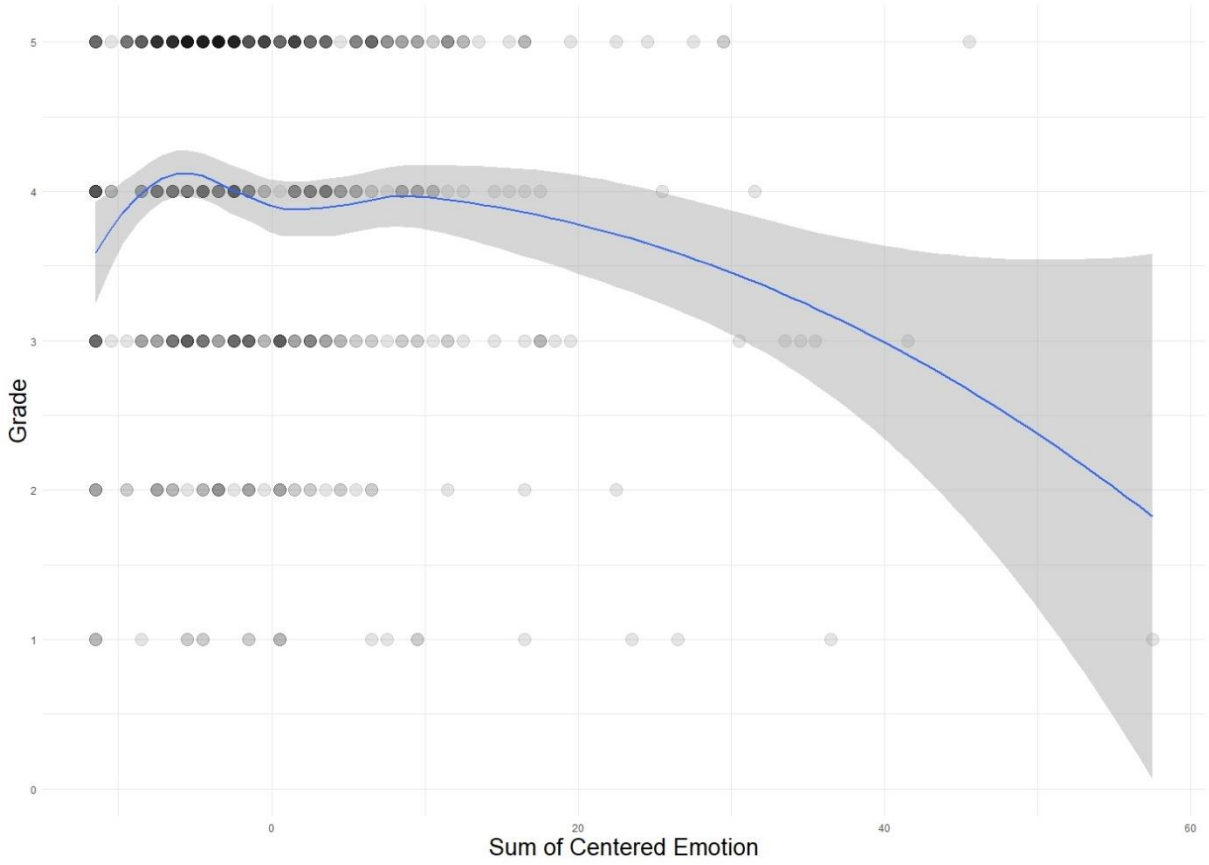
	Grade															
Predictors	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*
Intercept 1|2	0.155	0.463	0.063 – 0.385	**<0.001**	0.160	0.469	0.064 – 0.400	**<0.001**	0.129	0.322	0.068 – 0.242	**<0.001**	0.136	0.468	0.054 – 0.340	**<0.001**
Intercept 2|3	0.522	0.439	0.221 – 1.233	0.138	0.534	0.445	0.223 – 1.279	0.159	0.411	0.285	0.235 – 0.719	**0.002**	0.460	0.444	0.193 – 1.097	0.080
Intercept 3|4	2.191	0.437	0.931 – 5.155	0.072	2.189	0.443	0.919 – 5.218	0.077	1.463	0.280	0.846 – 2.531	0.174	1.960	0.441	0.826 – 4.652	0.127
Intercept 4|5	8.570	0.445	3.586 – 20.482	**<0.001**	8.352	0.451	3.450 – 20.219	**<0.001**	4.345	0.286	2.480 – 7.613	**<0.001**	7.750	0.448	3.219 – 18.659	**<0.001**
Linear model	1.300	0.077	1.117 – 1.512	**0.001**									2.499	0.275	1.458 – 4.281	**0.001**
Subjective preparation	1.583	0.089	1.329 – 1.886	**<0.001**	1.610	0.090	1.351 – 1.919	**<0.001**	1.442	0.083	1.224 – 1.698	**<0.001**	1.537	0.090	1.288 – 1.834	**<0.001**
Quadratic model					0.941	0.060	0.836 – 1.060	0.317	0.950	0.058	0.849 – 1.064	0.377				
Quadratic effect x preparation													0.807	0.086	0.682 – 0.956	**0.013**
Observations	622				622				622				622			
logLik	-776.66				-781.98				-848.76				-773.57			
Cox & Snell's R^2 / Nagelkerke's R^2	0.155/0.167				0.140/0. 0.151				0.134 / 0.142				0.164/0.176			
AIC	1567.319				1577.952				1709.517				1563.139			
BIC	1598.349				1608.983				1736.115				1598.602			

Model 1 Linear nested model; Model 2 Quadratic nested model; Model 3 Quadratic non-nested model; Model 4 Interaction between quadratic effect and subjective performance

3.3 Sum of Emotional intensity

On a visual inspection there seems to be a more quadratic relationship then the reported arousal. One potentially dangerous outlier can be observed in the lower right end. After an inspection it turned out that there were three responses that scored over 40, they were all correctly plotted.

Figure 4 Sum of emotion and grade



Sum of centred emotional intensity mean traced with blue line

Like the arousal models four models were built. Model 1 is a linear nested CLMM with the centered sum of emotions as a predictor and grade as dependent variable. The model proved non-significant with a OR of 0.99 CI 0.968 – 1.004 (p.136). Model 2 is a quadratic CLMM with the centered sum of emotions as a predictor and grade as dependent variable, this also accounting for nesting. The model is a significant predictor of grades with a OR of 1 in the overall model, the 1 is expected in a curve where the increase and decrease OR in the curve should cancel each other out CI 0.998 – 1.000 (p = 026). Model 3 is the non-nested quadratic CLM that proved significant with a OR of 0.999 CI 0.998 – 1.000 (p=.013). The last model

testing for interaction turned out non-significant OR of 1 CI 0.985 – 1.020 (p=.82). The BIC and AIC values favor model 2 as seen in table 3. Testing the Cox & Snell's R2 and Nagelkerke's R2 also favor the quadratic model. Model 2 also has the highest logLik-value.

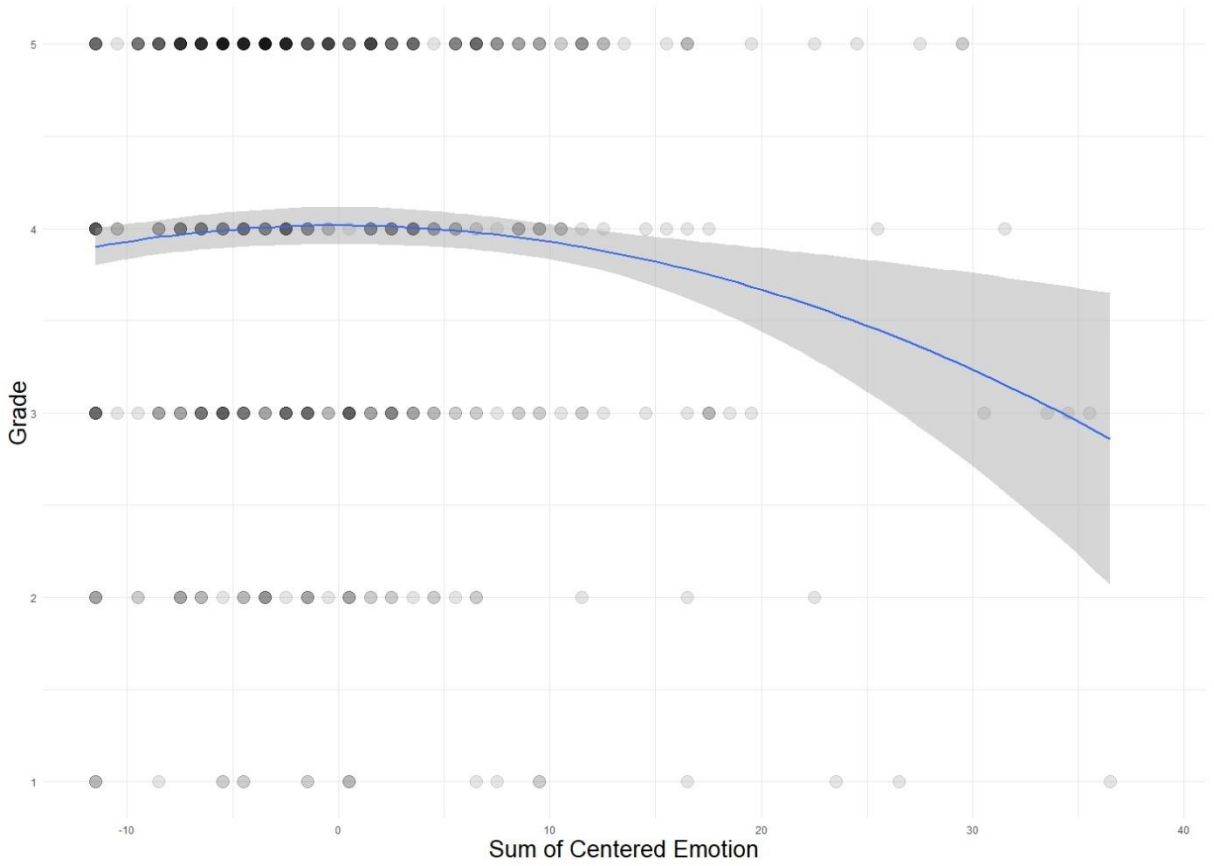
Table 3.Sum of emotional intensity model-comparison

	Grade															
Predictors	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*	*Odds Ratios*	*std. Error*	*CI*	*p*
Intercept 1|2	0.143	0.478	0.056 – 0.365	**<0.001**	0.129	0.481	0.050 – 0.330	**<0.001**	0.100	0.351	0.050 – 0.198	**<0.001**	0.141	0.481	0.055 – 0.363	**<0.001**
Intercept 2|3	0.488	0.449	0.202 – 1.176	0.110	0.445	0.450	0.184 – 1.075	0.072	0.329	0.306	0.180 – 0.600	**<0.001**	0.483	0.451	0.199 – 1.170	0.107
Intercept 3|4	2.009	0.445	0.840 – 4.806	0.117	1.848	0.445	0.773 – 4.420	0.168	1.195	0.298	0.667 – 2.141	0.549	1.990	0.447	0.828 – 4.783	0.124
Intercept 4|5	7.212	0.453	2.971 – 17.508	**<0.001**	6.649	0.452	2.741 – 16.134	**<0.001**	3.464	0.303	1.914 – 6.269	**<0.001**	7.139	0.455	2.925 – 17.421	**<0.001**
Linear model	0.986	0.009	0.968 – 1.004	0.136									0.980	0.027	0.929 – 1.035	0.474
Subjective preparation	1.537	0.097	1.271 – 1.859	**<0.001**	1.532	0.097	1.268 – 1.851	**<0.001**	1.376	0.090	1.153 – 1.641	**<0.001**	1.533	0.098	1.266 – 1.857	**<0.001**
Quadratic model					0.999	0.000	0.998 – 1.000	**0.026**	0.999	0.000	0.998 – 1.000	**0.013**				
Quadratic effect x preparation													1.002	0.009	0.985 – 1.020	0.823
Observations	548				548				548				548			
logLik	-686.85				-685.46				-736.22				-686.83			
Cox & Snell's R^2 / Nagelkerke's R^2	0.124/0.133				0.128/0.138				0.128 / 0.136				0.124/0.133			
AIC	1387.707				1384.921				1484.447				1389.657			
BIC	1417.851				1415.065				1510.285				1424.108			

Table 3 3Model 1 Linear nested model; Model 2 Quadratic nested model; Model 3 Quadratic non-nested model; Model 4 Interaction between quadratic effect and subjective performance

Considering the influential cases noted upon earlier, another set of models was built excluding the three outliers that scored above 40. The quadratic emotional sum model were still significant with OR 0.999 CI 0.998 – 1.000 (p=.043) with the lowest AIC score (1374.812), the lowest BIC score (1404.918), the highest logLik score (-680.410), and the highest R2, Cox and Snell (ML) = 0.126; Nagelkerke (Cragg and Uhler) = 0.136.

Figure 5 Quadratic model emotion



The Quadratic model depicting sum of emotional intensity filtered without influential cases

4.0 Discussion

The study has hypnotized that the YDL stands true in the context of academic performance. Arousal were measured in two different ways, one directly questioning the subjective emotional state, and one measured as the sum of reported intensity of each respective emotion. The hypothesis was partly correct. The subjective arousal gave a linear relationship, but the sum of emotions was indeed best explained by the quadratic model. As expected, the preparation confounder was a significant prediction of grade.

4.1 Arousal

There can be multiple reasons for the linear model to best explain the relationships. One can be the one item arousal measurement is insufficient to be considered valid and reliable, although it would reflect the subjective definition of every participant, the reliability could be a problem. When considered the measurement of arousal in the context of school situation, a 5-valued response would unlikely represent the pinnacle of human activation, rather a state of mind compared to similar exam situations. The potential of arousal would be for example higher in a situation where for example electric shock was administered like the earlier animal studies. But this level of arousal would be problematic from an ethical point of view, to complete with human subjects.

Another reason could be that the exams were too easy, and the linear result could reflect the same linear relationship observed in the original study when Dodson and Yerkes lowered the difficulty of the task. When observing the visualization, it can be observed that the most linear results came from the courses with skewed distribution of a high grade. The subjects that had more normal distribution of grades with a larger spread, also showed more quadratic tendencies. A post hoc test revealed that by removing cores 4 with the crooked distribution favoring the highest marks, the linear model prevailed with approximately the same OR of 1.37 CI $1.15 – 1.63$ ($p<.001$), with the lower AIC and BIC score. This argues against the theory of easy exams, and in addition the significant curvilinear relationship of emotional arousal cannot coexist with the linear if this was the case. A natural explanation of the linearity could be that the more the grade is valued by the individual, the higher level of arousal would be present, and since the grade is valued, the individual would have prepared

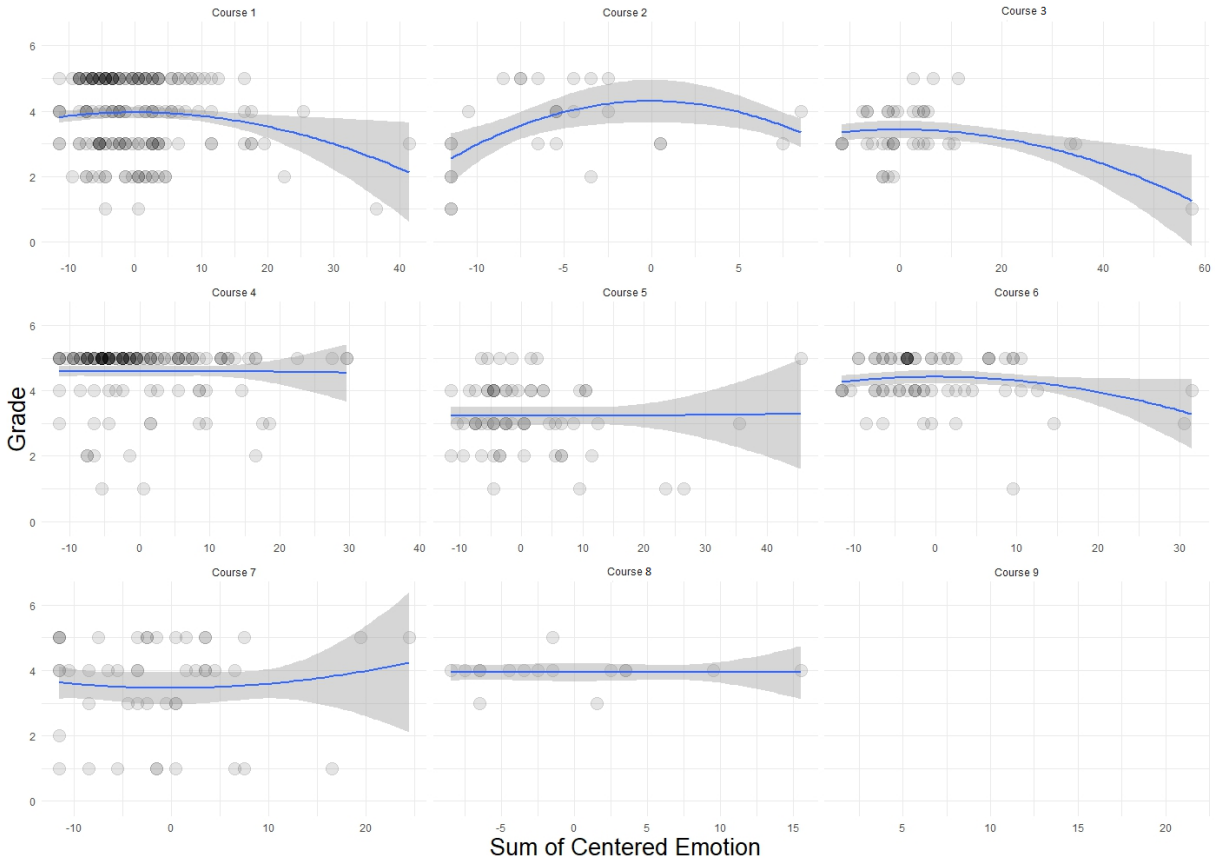
more thoroughly. Here the significant interaction-effect is helpful to explain. Subjective preparation did show a significant negative interaction with arousal OR 0.81 CI 0.682 – 0.956 (p=.013). This could be a quite natural “the more prepared the less aroused”. This argue against that if the individual value the grade/are more prepared, the more aroused. Still, the most significant predictor on higher grade is subjective preparation around OR 1.5 CI 1.351 – 1.919 (p.001), over all models.

The measurement could however be the reason. When confronted with a five-point Likert scale which was used for this variable, the participant would have little point of reference other than other exams in mind. It is also possible that all possible situational responses available in human nature cannot be generalized into one dimension of arousal, and the sum of emotion does a better job forcing introspective reflection and a more continuous measurement-tool.

4.2 Sum of emotional intensity

The quadratic model with the sum of emotional intensity did prove to be significant, and better model than the linear emotional model. The OR at 1 CI 0.998 – 1.000 (p.026) which is good for the hypothesis, where the increased odds for emotions should both increase and decrease, leaving them equalizing each-other out. The tests conducted all pointed towards the curvilinear model as the best model.

Figure 6 Quadratic models separated with emotion



Quadratic models with the sum of emotional intensity depicting each course separately

There is little research on the subjective emotional arousal against the YDL in human subjects, in animal-testing the term emotionality were used by Broadhursts & Law in mid-19th century (1957). Keeping in mind that emotionality is only the observable aspects of emotion and the Broadhurst-study measured emotionality by amount of defecation and urination in rats. This would be a less efficient operationalization of emotional arousal and the GEW takes a more discrete human-focused approach that supports the same hypothesis.

A reason the GEW became a significant model in contrast to arousal could be that it forces participants to reflect upon every feeling, including the positive ones which could be essential for the starting curve of the YDL. Eustress or beneficial stress is a theory that fits the results

of this study. The theory is one closely linked to the YDL although there is a difference between arousal, emotional activation and stress, it can be argued an overlap in a situation where the performance has consequences for the future (Selye, 1976b).

4.3 Strengths and limitations

The large number of participants is considered a strength and a lot more generalizable than some previous studies. We also wanted to avoid simple a correlation study and ANOVAs, with regression it gives a more accurate representation of causality. The methods of handling data are always improving and the ordinal CLMM's is considered a recognized and powerful scientific tool, valid in contemporary data-science. This cannot be said about all the 20th century research where some have aged badly.

There is some weakness to the study, that we did not have continuous dependent factors but rather ordinal could in some ways limiting the model to the 5 values of the grades. In the measurement of arousal there was only used a one-item Likert-scale with 5 points, resulting a 5-point independent and dependent factor, with the large number of participants it could be easier to make a type II error, or the failure to reject a false null hypothesis. In case of the linear relationship it would in theory be easier to reject the null hypothesis with two continuous variables. Also to quote two experts on the YDL, they stated that it «never saw a data set it couldnot explain» (Hancock referred in Teigen, 2019 p.476). What they meant was the previously accounted critique, that with a scientific frame around YDL is in constant change and the utilization of undefinable concepts it can be the go-to law for a large variety of phenomenon. This can be a weakness for the study concerning the subjectifies of emotional arousal, the lack of the sensitivity and specificity around the utilized questionnaire.

4.4 Conclusion

This study contributes scientific support to the YDL when defining arousal as the sum of emotional intensity. The inverted-U model proved significant and the best model to explain the data collected from the sum of emotional intensity. There was no significant linear model and no significant interaction between the amount of subjective preparation and the sum of emotional intensity. The curvilinear model predicted a lower grade when in a state of lower or

higher emotional arousal and supports the hypothesis that the YDL is valid for subjective emotional arousal and academic performance.

When measuring arousal however, a linear model was found to be the best model to explain the relationship between arousal and performance. The model suggested the more aroused, the better the grade, and a significant negative interaction was found between amount of subjective preparation and arousal. Although some research supports this notion the measurement of the arousal factor was operationalized with one single-item five-point Likert-scale, and a type I-error should also be considered.

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APPENDIX

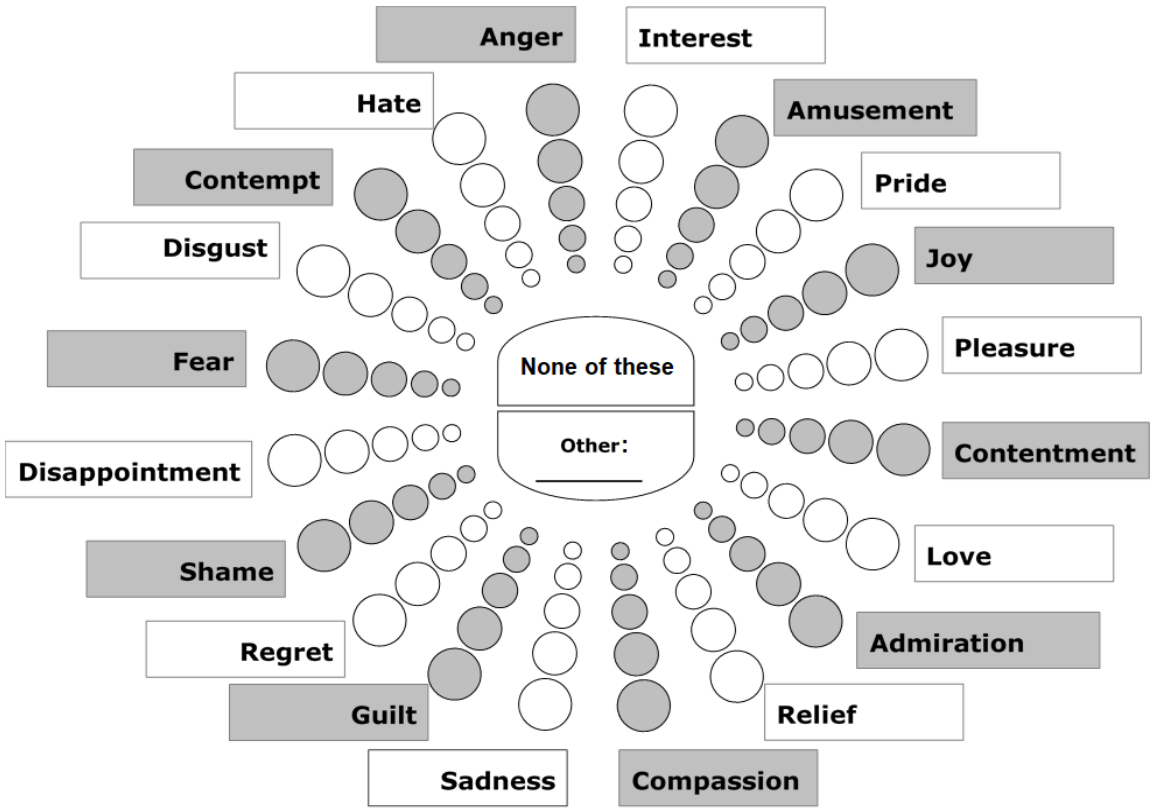
Questionnaire

Sometimes we are in a hightened emotional state, which can be associated with a broad range of emotions. In this study we propose to investigate how students experience these situations. <u>You can participate in the study even if you have already filled this questionnaire for another exam.</u>

To what extent are you now in a hightened emotional state? *Mark with an X the dot which best corresponds to the intensity of your state.*	***How well do you feel yourself prepared for this exam?*** *Mark with an X the dot which best corresponds to the what you feel about your preparation.*
	
Not at all O O O O O Very much	Not at all O O O O O Very much

What kind of emotions are associated with this feeling?

Please select <u>ONLY</u> those emotion(s) on the wheel, which best describe how you feel right now! Then determine the intensity of the respective emotion(s) and mark the intensity of the emotion(s) on one of the corresponding circles. Bigger circles represent stronger, while smaller circles represent weaker emotional experience. If you do not feel any emotion at all, please check the upper half circle in the center of the wheel (labeled "None"). If you experience an emotion that is very different from any of the emotions in the wheel, please check the lower half circle (labeled "Other").



Participation in the study is voluntary and you can discontinue at any time. The collected data will be anonymized, and will be made public as an effort to contribute to the open science movement, to facilitate collaboration and education in science. After the exam, we intend to ask your grade and points from the teacher. Filling out and

Do your best ☺

After you finished the exam, please fill the othe

Ethical Approval

EÖTVÖS LORÁND TUDOMÁNYEGYETEM
PEDAGÓGIAI ÉS
PSZICHOLÓGIAI KAR
KUTATÁSETIKAI BIZOTTSÁG

E·L·T·E

EÖTVÖS LORÁND UNIVERSITY
FACULTY OF EDUCATION
AND PSYCHOLOGY
RESEARCH ETHICS COMMITTEE

Reference number: 2017/395

Research Ethics Application Approval

Name of the Principal Investigator:	Dr. Tamás Nagy
His/her academic degree:	PhD
His/her workplace:	ELTE PPK, Department of Personality and Health Psychology
His/ her job title:	Assistant professor
His/her e-mail address:	nagy.tamas@ppk.elte.hu
Title of the research:	Stress and emotions in exam situations
Further researchers (e.g.student):	Beáta Bőthe, Éva Gál, Dr. Gábor Orosz, Sára Posta, Thomas Pedersen, Erlend Holmberg Dørum, Mari Louise Berge
Expected dates of the beginning and the end of the research:	08. 06. 2018. – 31. 12. 2019.

The Research Ethics Committee of the Faculty of Pedagogy and Psychology (ELTE) grants permission to carry out the above study. This decision is based on the evaluation of the referenced Application submitted to the Research Ethics Committee.

Budapest, 08. 06. 2018.

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Research Ethics Committee
Chair or Acting Member

Eötvös Loránd University
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Permission to data processing
Details concerning the rights of data subjects

For the purposes of this information sheet (and of GDPR), **'data subject' shall mean** a natural person who has been identified by reference to specific personal data, or who can be identified, directly or indirectly; **'personal data'** means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person (Article 4. ff GDPR and Section 3. of InfoAct).

Rights of the data subject according to Chapter III. of the GDPR

1. Transparent information, communication and modalities for the exercise of the rights of the data subject;
2. Right of access by the data subject;
3. Right to erasure ('right to be forgotten'), right to restriction of processing;
4. Information to be provided where personal data have not been obtained from the data subject;
5. Right to data portability (if we process your data on the basis of your consent/contract the processing is carried out by automated means.);
6. Right to object;
7. The right not to be subject to a decision based solely on automated processing, including profiling;
8. The right to legal remedy: in the case of any breach of your rights, you can turn to the data protection officer of Eötvös Loránd University, to the National Authority for Data Protection and Freedom of Information, or you can sue a claim to the court.

You can read the explanation of the rights below:

1. Transparent information, communication and modalities for the exercise of the rights of the data subject (Article 12-14 of GDPR)

With this information sheet, the controller provides the information relating to processing to the data subject referred to in GDPR.

If the data subject asks, further detailed oral information can be given, if the data subject proves his or her identity.

2. Right of access by the data subject (Article 15 of GDPR)

The data subject have the right to obtain from the controller confirmation as to whether or not personal data concerning him or her are being processed, and, where that is the case, access to the personal data and the following information:

(a) the purposes of the processing;

(b) the categories of personal data concerned;

(c) the recipients or categories of recipient to whom the personal data have been or will be disclosed, in particular recipients in third countries or international organisations;

(d) where possible, the envisaged period for which the personal data will be stored, or, if not possible, the criteria used to determine that period;

(e) the existence of the right to request from the controller rectification or erasure of personal data or restriction of processing of personal data concerning the data subject or to object to such processing;

(f) the right to lodge a complaint with a supervisory authority;

(g) where the personal data are not collected from the data subject, any available information as to their source;

(h) the existence of automated decision-making, including profiling, referred to in Article 22(1) and (4) of GDPR and, at least in those cases, meaningful information about the logic involved, as well as the significance and the envisaged consequences of such processing for the data subject.

3. Rectification and erasure (Article 16 of GDPR)

2

3.1. Right to rectification (Article 16 of GDPR)

3.2. Right to erasure (‘right to be forgotten’) (Article 17 of GDPR)

The data subject shall have the right to obtain from the controller without undue delay the rectification of inaccurate personal data concerning him or her. Taking into account the purposes of the processing, the data subject shall have the right to have incomplete personal data completed, including by means of providing a supplementary statement.
The data subject shall have the right to obtain from the controller the erasure of personal data concerning him or her without undue delay and the controller shall have the obligation to erase personal data without undue delay where one of the following grounds applies:
(a) the personal data are no longer necessary in relation to the purposes for which they were collected or otherwise processed;
(b) the data subject withdraws consent on which the processing is based according to point (a) of Article 6(1), or point (a) of Article 9(2) of GDPR, and where there is no other legal ground for the processing;
(c) the data subject objects to the processing pursuant to Article 21(1) of GDPR and there are no overriding legitimate grounds for the processing, or the data subject objects to the processing pursuant to Article 21(2);
(d) the personal data have been unlawfully processed;
(e) the personal data have to be erased for compliance with a legal obligation in Union or Member State law to which the controller is subject;
(f) the personal data have been collected in relation to the offer of information society services referred to in Article 8(1) of GDPR.
3.3. Right to restriction of processing (Article 18 of GDPR)
The data subject shall have the right to obtain from the controller restriction of processing where one of the following applies:
(a) the accuracy of the personal data is contested by the data subject, for a period enabling the controller to verify the accuracy of the personal data;

(b) the processing is unlawful and the data subject opposes the erasure of the personal data and requests the restriction of their use instead;
(c) the controller no longer needs the personal data for the purposes of the processing, but they are required by the data subject for the establishment, exercise or defense of legal claims;
(d) the data subject has objected to processing pursuant to Article 21(1) of GDPR pending the verification whether the legitimate grounds of the controller override those of the data subject.
The controller shall provide information on action taken on a request under Articles 15 to 22 to the data subject without undue delay and in any event within one month of receipt of the request. That period may be extended by two further months where necessary, taking into account the complexity and number of the requests. The controller shall inform the data subject of any such extension within one month of receipt of the request, together with the reasons for the delay. Where the data subject makes the request by electronic form means, the information shall be provided by electronic means where possible, unless otherwise requested by the data subject. (Article 12.3 of GDPR)
4. Notification obligation regarding rectification or erasure of personal data or restriction of processing (Article 19 of GDPR)

The controller shall communicate any rectification or erasure of personal data or restriction of processing carried out in accordance with GDPR Article 16, Article 17(1) and Article 18, to each recipient to whom the personal data have been disclosed, unless this proves impossible or involves disproportionate effort. The controller shall inform the data subject about those recipients if the data subject requests it.
5. Right to data portability (Article 20 of GDPR)

The data subject shall have the right to receive the personal data concerning him or her, which he or she has provided to a controller, in a structured, commonly used and machine-readable format and have the right to transmit those data to another controller without hindrance from the controller to which the personal data have been provided, where:
(a) the processing is based on consent or on a contract; and
(b) the processing is carried out by automated means.
In exercising his or her right to data portability, the data subject shall have the right to have the personal data transmitted directly from one controller to another, where technically feasible.
The exercise of this right shall be without prejudice to the right to be forgotten. 3

6. Right to object (Article 21 of GDPR)

The data subject shall have the right to object, on grounds relating to his or her particular situation, at any time to processing of personal data concerning him or her which is based on point (e) or (f) of Article 6(1) of the GDPR, including profiling based on those provisions. The controller shall no longer process the personal data unless the controller demonstrates compelling legitimate grounds for the processing which override the interests, rights and freedoms of the data subject or for the establishment, exercise or defence of legal claims.

7. Automated individual decision-making, including profiling (Article 22 of GDPR)

The data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her.

This provision shall not apply if the decision:

(a) is necessary for entering into, or performance of, a contract between the data subject and a data controller;

(b) is authorised by Union or Member State law to which the controller is subject and which also lays down suitable measures to safeguard the data subject's rights and freedoms and legitimate interests; or

(c) is based on the data subject's explicit consent.

In this case, he data controller shall implement suitable measures to safeguard the data subject's rights and freedoms and legitimate interests, at least the right to obtain human intervention on the part of the controller, to express his or her point of view and to contest the decision.

8. Legal remedy – alternative possibilities

8.1. Data protection officer (Article 24 of InfoAct, Article 39 of GDPR)

The data protection officer has to monitor compliance with GDPR, with other Union or Member State data protection provisions and with the policies of the controller or processor in relation to the protection of personal data, including the assignment of responsibilities, awareness-raising and training of staff involved in processing operations, and the related audits (Article 39 of GDPR)

Data protection officer of the University:

Dr. Kinga Rigó
Rector's Cabinet
1053 Budapest, Ferenciek tere 6.
Tel.: +3614116500/2855.
Email: strategia@rk.elte.hu

8.2. Investigation of the National Authority for Data Protection and Freedom of Information (Article 52-58 of InfoAc), 57., 77. Article of GDPR

Any person shall have the right to notify the Authority and request an investigation alleging an infringement relating to his or her personal data or concerning the exercise of the rights of access to public information or information of public interest, or if there is imminent danger of such infringement.

The Authority may refuse the notification without examination thereof as to merits if the infringement alleged in the notification is considered minor, or the notification is anonymous. You can find further reasons for rejection in Section 53. of the InfoAct.

National Authority for Data Protection and Freedom of Information
1125 Budapest,
Szilágyi Erzsébet fasor 22/c.
www.naih.hu
Tel.: +36-1-391-1400

8.3. Right to an effective judicial remedy against a controller or processor (Section 22. Of InfoAct. Article 79 of GDPR)

Without prejudice to any available administrative or non-judicial remedy, including the right to lodge a complaint with a supervisory, each data subject has the right to an effective judicial remedy where he or she considers that 4

his or her rights under GDPR have been infringed as a result of the processing of his or her personal data in non-compliance with GDPR.

Proceedings against a controller or a processor shall be brought before the courts of the Member State where the controller or processor has an establishment. Alternatively, such proceedings may be brought before the courts of the Member State where the data subject has his or her habitual residence, unless the controller or processor is a public authority of a Member State acting in the exercise of its public powers.

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