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The psychological response to a low carbohydrate ketogenic diet in combination with a six-week strength training protocol

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The Psychological Response to a Low Carbohydrate Ketogenic Diet in Combination with a Six-Week Strength Training Protocol

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Table of Contents

Acknowledgments……..……ii

List of Tables…….....….iv

List of Figures…….....v

Abstract……..vi

Chapter 1: Introduction & Review of Literature……..……..……..…....1

Chapter 2: Methodology & Research Design.....7

Chapter 3: Submission to the *Journal of Strength and Conditioning Research*….....14

Appendixes…….……...……....34

Appendix A: 1-RM Testing Procedure

Appendix B: Six-Week Strength Training Protocol

Appendix C: Hospital Anxiety and Depression Scale

Appendix D: Borg's Rate of Perceived Exertion

Appendix E: Profile of Mood States

List of References.....42

List of Tables

Table 1 – Baseline demographic data for male college students on either an ad libitum or low carbohydrate ketogenic diet

Table 2 – Profile of Mood States (POMS) statistical analysis output of Total Mood Disturbance (TMD) scores for male college athletes on an ad libitum or low carbohydrate ketogenic diet over six weeks

Table 3 – Pre and post intervention 1RM for bench press, back squat and deadlift for male college students on either an ad libitum or low carbohydrate ketogenic diet

Table 4 – Mean descriptive statistical analysis of FIRs for male college students adhering to either an ad libitum or low carbohydrate ketogenic diet

List of Figures

Figure 1 – Hospital Anxiety and Depression Scale (HADS) Anxiety scale estimated scores of college males on an ad libitum or low carbohydrate ketogenic diet over a six-week intervention period

ABSTRACT

The aim of the present study was to determine whether or not long-term adherence to a Low-Carbohydrate Ketogenic Diet (LCKD) combined with a powerlifting strength training protocol could produce a positive psychological response. This six-week randomized control trial consisted of a treatment (LCKD) group (7% carbohydrates, 50% fat and 45% protein) and a control (CON) group (ad libitum). Both groups completed a validated powerlifting training protocol, as well as the Hospital Anxiety and Depression Scale and the Profile of Mood States. Multivariate testing and general linear modeling statistical analyses were used to compare psychological response between groups ($p < 0.05$) and found that there was a significant decrease in anxiety over the duration of six-weeks among both groups. No other psychological responses, including negative responses, were found to be significant. All participants significantly improved one-repetition max bench press, back squat, and deadlift ($p < 0.05$). The main findings of this study suggest that some positive psychological responses exist from long-term LCKD adherence, as well as potential increases in strength performance.

Chapter 1

Introduction:

To date, the effects of carbohydrate-restricted diets on physical performance and other metabolic variables has been studied extensively. However, research is presently lacking on the effects of low-carbohydrate diets and the resultant psychological effects[2,5,17,20,22].

The majority of studies are very similar in protocol, however variances in each study make it difficult to interpret which LCKD protocol is most effective[17,21]. Among these variances, there a few that resonate most prominent. The first being an accurate definition of what specifically a low-carbohydrate diet must consist of to be categorized as such[20,21]. A common definition is a diet low enough in carbohydrates to begin producing ketones in the urine or a diet that consumes less than 20-50 grams/day of the macronutrient to produce metabolic change[20,21].

Other variances include a trial period long enough to allow for these metabolic changes to occur, as they vary individually, as well as its effect on lean body mass and dietary changes in regards to the remaining macronutrients[2,5,22,23]. Specifically, studies have shown have inconsistencies in fat and protein macronutrient intake, as well as total dietary caloric intake. This makes it difficult to determine when exactly an individual begins producing urinary ketones; however, it is typically seen within a week to 10 days[2,21].

Low-Carbohydrate Ketogenic Diets have been gaining popularity recently among several populations due to the metabolic shift induced by severe carbohydrate restriction, most notably in weigh-class oriented sports such as powerlifting and judo[9,21,22]. This

carbohydrate restriction induces ketosis by limiting available glucose to tissues and induces the production of urinary ketones, or ketone bodies[21,22]. Ketone bodies are resultant by-products of partial oxidation of fatty acids in the liver when glucose availability is limited or impaired[20,21].

When adhering to a LCKD, the primary fuel source is shifted from carbohydrates to fat stores[20,21]. This metabolic shift causes approximately 70% of energy to come from the breakdown of fatty acids, 20% from ketone bodies and the remaining 10% coming from glycogen stores[20-23]. This fuel shift has demonstrated an increase in muscular uptake of plasma free fatty acids and utilization of intramuscular triglycerides, resulting in a reduction of carbohydrate oxidation and muscle glycogenolysis[20]. In terms of physical performance, even with reduced glycogen availability, research has found that intramuscular triglycerides are a sustainable energy source during activity[20-23].

While this study will be assessing several of the physical and metabolic aspects of adhering to a long-term LCKD, it will also be addressing an aspect few others studies have addressed in detail and that is the psychological response of adhering to LCKD in combination with strength training[7,9,16,23]. Several different low-carbohydrate diet studies have shown both negative and positive psychological responses to varying types of intervention and training[2,7,9,13,20]. Study variation makes it difficult to generalize consistent findings regarding a psychological response and associated symptoms to a given population, specifically strength and competitive athletes.

In limited exercise studies examining the psychological aspect, negative psychological associations and symptoms were found in response to carbohydrate-restricted diets and interventions[9,16,21-23]. These negative associations were believed to be

in response largely due to adapting to dietary changes and caloric intake restriction[9,16,21]. Studies featuring exercise-related interventions, including resistance and aerobic training, in combination with low-carbohydrate diets had a greater prevalence of associated side effects[9,10,23]. These side effects include irritability, loss of reported favorite foods, loss of comfort in eating, feelings of deprivation, decreased self-esteem, insomnia and physical and cognitive symptoms all of which contribute to an increase in depression and depression-like symptoms[5,7,9,16,21,23].

It is not uncommon for individuals adhering to a low-carbohydrate diet to experience negative psychological associations while adapting to the dietary changes[8]. Oftentimes, carbohydrate intake restriction in combination with physical activity will produce increased levels of fatigue[9,21-23]. This fatigue is largely due to the body's adaptation to the reduced energy intake and can induce several other negative responses[2,5,13,17].

Conversely, literature has also indicated the opposite and found that low-carbohydrate diets had a positive psychological effect on the individuals participating[9,10-13,22]. While the exact reason for these positive associations and responses is not yet clear, there is a great deal of evidence supporting resultant positive psychological responses from low-carbohydrate interventions combined with exercise[7,9,10,14,22]. It is also well studied that consistent exercise two to three times a week reduces depression-like symptoms including anger, stress and other related symptoms[12].

Positive psychological responses included improved self-esteem and associated symptoms including better overall mood and wellbeing, improved satiety, less confusion, greater sense of coherence, decreased stress and anger as well as several other

improvements[5,10,11,20]. All of these positive psychological responses notably decreased depression and depression-like symptoms in participants across most populations studied[9,11,14]. However, over the duration of these studies, a majority of participants returned to baseline levels or improved as the study progressed[6].

In 2013, Sawyer et al. performed an exercise study implementing a LCKD to a study group over a week time period[17]. While the exact keto-adaption period is relatively subjective and may not have occurred in all participants in this study, the study did assess some of the psychological aspects in those adhering to the LCKD protocol[17]. The study was able to demonstrate increased satiety in participants associated with the treatment diet as well as other physiological effects including weight loss and decrease in fat mass. However, it also showed increased fatigue in some participants making it difficult to generalize a psychological response to the dietary and strength interventions[17].

Furthermore, a recent study focusing on judo athletes and contest preparation sought to determine whether or not a severe carbohydrate restricted diet would have a negative influence on both psychological and physiological responses to training[9]. Again, no keto-adaption period was defined, as the trial was only seven days; however, psychological responses were still difficult to generalize[9]. Participants reported mood alterations including increased anger and fatigue, as well as decreased motivation after competition[9]. However, the research revealed there was no statistical significance of any depression-like symptoms resulting from the dietary adherence and training protocol, indicating that a generalized psychological response still warrants further research[9].

While it is well studied that low-carbohydrate diets combined with exercise will result in a ketogenic shift, it is not clear which dietary and exercise protocol is most

effective as studies differ in protocol, methods and populations making generalizing findings very difficult. It is also unclear as to where the threshold for keto-adaption begins as it varies individually and the psychological response from such studies is even less documented. Conclusions regarding both metabolic and psychological aspects of this dietary and exercise combination could prove to be very beneficial in the application of LCKDs to a variety of populations seeking to use alternative training methods, especially those in weight class-oriented sports.

Limitations and Delimitations:

Several limitations exist among recent studies, including an identified keto-adaption period, varying intake of protein and fat, as well as a clear definition of LCKD. In terms of psychological response, limited studies have included a psychological aspect, and those that did, have shown mixed results making any generalizations difficult. Additionally, a great deal of recent literature has focused on varying populations and not specifically on strength athletes. Delimitations of the present research include only studying males, ad libitum diet with only carbohydrates restricted and self-report of data by participants.

Purpose:

Present aims of this research seek to determine whether or not there is a positive psychological response to a long-term LCKD and strength training protocol. Additionally, current research also seeks to determine whether or not long-term

adherence to this dietary strategy in combination with strength training can positively influence pre-competition training of athletes.

Therefore, the purpose of this aspect of the study is designed to assess the psychological response of individuals adhering to a six-week LCKD while also maintaining a rigorous strength program in effort to increase lean body mass, decrease fat mass and maintain or improve strength.

Hypothesis:

It may be then hypothesized that individuals will have a positive psychological response as a result of the LCKD and strength training will decrease feelings of depression and depression-like symptoms including improvement of self-esteem, overall well-being and other associated symptoms.

Chapter 2

Research Design:

The purpose of this study is to examine the effects a low carbohydrate ketogenic diet (LCKD) has on psychological response in strength trained males. This is a six-week randomized controlled trial, with a carbohydrate-restricted diet intervention group and a normal diet control group. The LCKD itself will be composed of less than 7% of kilocalories from carbohydrates, approximately 50% from fat, and approximately 45% from protein. CHO consumption will not exceed 50g per day for any participant consuming the LCKD. The psychological response to the combination of the LCKD and the training will be measured using the Hospital Anxiety and Depression Scale (HADS), Profile of Mood States (POMS), as well the Borg Rating of Perceived Exertion Scale (RPE)[4,16,19]. The results from the two psychological surveys will be gathered throughout the intervention and assessed to determine whether the LCKD had a positive or negative psychological response, specifically in the reduction of depression and depression-like symptoms associated with such interventions.

Participants

Participants will be resistance-trained males, ages 18-25. For purposes of this study, resistance-trained is defined as having engaged in resistance exercise three to five times per week for at least one year. They will need to have sufficient experience with resistance training, which will be evaluated through individual assessment of proper lifting technique by both researchers and a Certified Strength and Conditioning Specialist. Participants with current injuries that affect power-lifting performance and

health conditions that put the participant at risk will be excluded. Participants must be free of diagnosed cardiovascular disease and fall into the "low" risk category, as defined by the American College of Sports Medicine (ACSM)[1]. Participants must also be free of any clinical psychological disorders, such as depression or associated disorder. Participants currently taking any medication that affects body composition will be excluded from participating in the study. Additionally, participants currently taking any dietary supplements or ergogenic aids will need to discontinue consumption seven days before baseline testing and continue for the duration of the study.

Participants will be recruited campus-wide via JMU bulk email request, University Recreations (UREC), and also through individual presentations in the general education health courses of (e.g., GHTH100). Advertisements will be posted in the UREC facility, and personal recruitment will take place in each of the GHTH100 sections. Persons interested in participating will then be screened to see if they meet the minimum criteria for entrance into the study. Participation is entirely voluntary. Participants will be informed that they may withdraw from the study at any time without consequences of any kind. Participants will be also be directed to seek assistance through James Madison University's Counseling Center should any adverse psychological or depression-like symptoms become apparent. Additionally, this study and research protocol has been reviewed and approved by the James Madison University Institutional Review Board.

Methods and Procedures

This study will be a six-week randomized controlled trial with an intervention group that consumes a LCKD and a control group that consumes a habitual diet, while both engage in power lifting training. The independent variable is the treatment diet and the dependent variables are body composition, power lifting performance and the psychological response. Once informed consent is obtained, participants will be randomly assigned to either the control group or the LCKD intervention group. Testing and training will take place as follows:

Timeframe**:**

Subject recruitment will begin at the start of the Fall 2014 semester and will last four weeks. Initial data collection and baseline testing will take place the week following the fourth week of recruitment. The six-week intervention will begin after the baseline-testing week. Post intervention testing will immediately follow the sixth week of intervention.

Familiarization:

Participants in the LCKD group will undergo detailed instructions and guidance on how to follow a LCKD prior to the start of the intervention. They will also receive instructions on how to properly fill out a dietary food intake record, which will be analyzed via Nutrition Data System for Research software in the Sensory and Diet Evaluation Lab. Resistance training evaluations will also be done during the baseline week prior to intervention and will include instructions on proper form and techniques of

all exercises included in each assigned workout. The instruction will be performed by a Certified Strength and Conditioning Specialist.□□□

Baseline Testing:

Data collection during the baseline week will include one-repetition maxes (1-RM) for all three lifts, body weight and height measurement, and dual x-ray absorptiometry (DXA) scan for the assessment of body composition. All power lifting testing will take place in the UREC weight room facility. One repetition max lifts will be tested and recorded by the researcher using 1-RM testing protocol as validated by the National Strength and Conditioning Association (Appendix A)[3]. Participants will also complete the first portion of the psychological evaluation including the HADS and the POMS during baseline testing.

Psychological Testing Procedures

Anxiety and depression will be assessed using the HADS (Appendix C). This instrument is ideal for monitoring anxiety and depression throughout any kind of treatment[19]. It accurately reflects and distinguishes changes in both anxiety and depression in response to emotional or physiological stress or change with results falling under normal, mild, moderate and severe[19]. HADS has also been validated across varying populations and interventions[19].

Perceived exertion will be assessed using the RPE Scale (Appendix D). Participants responded according to how they felt as a result of the physical activity, or in this scale, strength-training protocol and associated diet[4]. The scale ranges from 6 to 20

with participants responding in relation to how hard they felt they were working in order to complete the desired exercise[4]. The RPE scale suggests that a rating between 12 and 14 indicates a moderate level of physical exertion[4].

The POMS is a validated self-report measure effective in quick assessment of fluctuating feelings and mood states applicable in a variety of settings including research and athletic settings (Appendix E)[16]. It is composed of seven scales that combine to give a Total Mood Disturbance (TMD) score[16]. These scales are anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension-anxiety, vigor-activity and friendliness[16]. TMD scores range from -32 to 200 with lower scores indicative of more stable individuals and higher scores indicative of less stability and distress[16]. Results may be combined over multiple assessments for accurate analysis with the expectation of improvement over time[16].

Training Protocol:

Each participant will be required to participate in four training sessions a week, for six weeks. The training protocol used in this study was previously validated by Crewther, Heke, Keough and published in *The Journal of Sports Medicine and Physical Fitness*[8]. Results from the previous study show 11% gains in bench press max, 13% gains in back squat, and 13% gains in deadlift when adhering to the validated training protocol. The validated protocol includes two workouts that are alternated each day (Appendix B). Participants are prohibited from engaging in any other excessive physical activity during the study. Workout spreadsheets will be filled out daily to ensure compliance with training. There will also be one mandatory supervised training session with one of the

researchers every week. During this session, the researcher present will utilize RPE to monitor the participant's level of perceived exertion. Perceived rate of exertion will also be monitored throughout the duration of the training intervention.

Dietary Protocol:

Both groups will have a mandatory dietary instruction session prior to beginning the study. The sessions will go over how to accurately keep dietary food intake records. The normal diet group will maintain their current diets and serve as the controls. In addition, the LCKD group will learn about low carbohydrate foods vs. high carbohydrate foods. They will be provided low carbohydrate meal and snack ideas, as well as grocery shopping tips. The LCKD group will be instructed to consume less than 7% of total calories from carbohydrate, 50% from fat, and 45% from protein. Carbohydrates are restricted to no more than 50g per day per participant to ensure participants begin producing ketone bodies.

The diet intervention will last six weeks. Dietary compliance will be monitored by mandatory daily self-recorded dietary food intake records that will be turned in weekly. The food intake records will be analyzed using Nutrition Data System for Research software in the Sensory and Diet Evaluation Lab. Additionally, urinary ketones will be monitored to check compliance. Urine will be analyzed using a Clinitek Status Plus Urinalysis machine for presence of ketone bodies to determine adherence. If participants begin to experience negative psychological effects due to the diet, they will be directed to seek assistance from James Madison University's Counseling Center.

Post-Intervention Testing:

Data collection procedures will be the same as baseline testing procedures for 1-RM testing, body composition assessment and psychological assessment during post-intervention testing.

Data Analysis:

Data will be analyzed using the SPSS 21.0 statistical software package (SPSS Inc., Chicago, IL). Descriptives will be used to establish mean and +/-SD. Multivariate testing and general linear modeling will be used to analyze the psychological scales. Data will also be analyzed to determine whether or not mood and depression contribute to overall success of the intervention, as well as any other potential correlations that may become evident.

The independent variable is the treatment diet and the dependent variables are body composition, performance, and the psychological response. At the end of the study, all information that matches up individual respondents with their answers will be destroyed.

Chapter 3

SUBMISSION TO THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH

INTRODUCTION

To date, literature has revealed the effects of carbohydrate-restricted diets on improving physical performance and other metabolic variables including weight loss[2,5,7]. However, present research is deficient when examining the effects of low-carbohydrate diets on psychological response when combined with associated exercise protocols[6,7,9,10]. Recently, Low-Carbohydrate Ketogenic Diets (LCKD) have emerged as a growing area of interest, most notably in weight-class oriented sports such as competitive power lifting, wrestling, judo and boxing as a means of weight loss and preparation for competition[4,9,14]. While many studies involving athletes and LCKD's have focused on variables such as performance, metabolism and body composition, the associated psychological response has not been measured extensively[2.5,10,14,17].

The majority of these studies are very similar in protocol; however, variances among each study make it difficult to generalize an accurate definition of what a LCKD must consist of to be categorized as such[15.18.20]. A common definition describes a diet low enough in carbohydrates to begin producing ketones in the urine or a diet that consumes less than 20-50 grams/day (approximately 7% of total calories) of carbohydrates to induce metabolic change[5,6,18,20]. Along with an accurate definition, studies have also revealed variance in a trial period long enough to allow metabolic change to occur, as this has been found to vary individually[2,3,5,15]. Additionally, studies have exposed inconsistencies in remaining fat and protein macronutrient intake, as well as total dietary

caloric intake[18,20,21]. These variance present several difficulties in determining exactly when an individual may begin producing urinary ketones; however, it is typically seen within a week to 10 days in most studies[2,20,21].

As mentioned, LCKD's have been gaining popularity among several populations due to the subsequent metabolic shift causing the primary fuel source to shift from carbohydrates to the breakdown of fat stores. This shift allows for approximately 70% of energy to come from the breakdown of fatty acids, 20% from the production of ketone bodies and the remaining 10% coming from glycogen stores ultimately resulting in an increase of muscular uptake of plasma free fatty acids and reduction of both carbohydrate oxidation and muscle glycogenolysis[18,20]. However, during this metabolic shift, very few studies have addressed in detail the associated psychological response, specifically depression and depression-like symptoms, of adhering to a LCKD in combination with a strength training intervention[9,10-12,17]. Varying studies have shown both negative and positive psychological responses among athletes adhering to a LCKD or other carbohydrate-restricted interventions, making it difficult to generalize consistent findings regarding an associated psychological response and related side effects[8,10,11,15].

In limited exercise studies examining a psychological component, mixed results have been found showing either a positive or negative psychological response while adhering to a LCKD or carbohydrate-restricted diet[6,7,9-11,14]. Negative responses were more prevalent among exercise studies and are believed to be due primarily to dietary adaption, caloric intake restriction and increased levels of anxiety and fatigue[7,9-11]. Side effects included an increase in depression and depression-like symptoms among participants, including irritability, feelings of deprivation, decreased self-esteem, as well

as other physical and cognitive symptoms[5,9,14,20]. Conversely, while still unclear, some studies indicated a positive psychological response among participants adhering to carbohydrate-restricted interventions[5,9-12,20]. Positive side effects showed a decrease in depression and depression-like symptoms, including improved self-esteem and mood, improved satiety, greater sense of coherence and decreased levels of stress and anger[5,9,10,19-21]. However, it should be noted that over the duration of these studies, a majority of participants either returned to baseline levels or retained improvements as the study progressed[6,20].

The current study focused on assessing the psychological response of trained individuals adhering to a LCKD and validated six-week strength training protocol with emphasis on the power lifts used in a competitive setting including bench press, squat and deadlift. The research attempted to identify any positive or negative side effects as they relate to depression or depression-like symptoms as these conclusions may prove to beneficial in the application of LCKD's and associated training protocol to a variety of populations seeking alternative training or preparation methods. The purpose of the current study was to determine whether or not there is a positive psychological response to a long-term LCKD and strength training protocol in efforts to improve strength and training preparations of competitive athletes. It may be then hypothesized that individuals will have a positive psychological response as a result of LCKD and strength training combination and will decrease feelings of depression and depression-like symptoms.

METHODS

Experimental Approach to the Problem

This is a six-week randomized controlled trial with a carbohydrate-restricted diet intervention group and a normal diet control group. The LCKD group was instructed to adhere to a diet composed of less than 7% of total kilocalories from carbohydrates, approximately 50% from fat, and approximately 45% from protein. Carbohydrate consumption was not to exceed 50g per day. The control (CON) group was instructed to maintain an ad libitum diet. Both groups were required to maintain and follow the same validated strength training protocol for the duration of the study.

The psychological response to the combination of the LCKD and the training was measured using the Hospital Anxiety and Depression Scale (HADS) and the Profile of Mood States (POMS). The results from both psychological surveys were gathered throughout the intervention and assessed to determine whether the LCKD had a positive or negative psychological response, specifically in the reduction of depression and depression-like symptoms associated with such interventions. The independent variables were the assigned diet and powerlifting protocol and the dependent variables were powerlifting performance and psychological response.

Participants

Participants were recruited through the university bulk-email system, the university recreation center and individual recruitment in the general education health courses. This study initially included 34 resistance-trained males with a mean age of 20.0 ± 1.7 (Table 1). All participants were informed of potential risks, provided informed consent and completed an exercise history questionnaire prior to the start of the study. Inclusion criteria included sufficient experience with resistance training, which was

evaluated through individual assessment of proper lifting technique as outlined by the National Strength and Conditioning Association[3] under the supervision of a Certified Strength and Conditioning Specialist and regularly engaging in resistance training three to five times per week. Any subjects with current injuries that affect powerlifting performance and/or health conditions that put them at risk were excluded from this study. Participants had to be free of diagnosed cardiovascular or metabolic disease and fall into the "low risk" category as defined by the American College of Sports Medicine[1]. Participants currently taking any dietary supplements or ergogenic aids were instructed to discontinue consumption one week prior to baseline testing and abstain for the duration of the study regardless of treatment assignment.

All methods and procedures utilized in this study were approved by the university's Institutional Review Board prior to data collection.

Procedures

This study consisted of a six-week randomized control trial with participants randomly assigned to either an intervention group adhering to a LCKD or a CON group adhering to an ad libitum diet. Both the intervention and control group were instructed to complete the same validated powerlifting training protocol.

Familiarization

Prior to the beginning of the intervention period, all participants were required to attend an informational meeting to discuss group assignment and instructions regarding dietary compliance. All participants were instructed to refrain from the use of unapproved

supplements or ergogenic aids. The control group was instructed to maintain their diet as normal throughout the study. The intervention group was given detailed instruction and provided supplementary information on how to follow and maintain a LCKD including sample menus highlighting low-carbohydrate options available on campus, list of both low- and high-carbohydrate foods and a list of approved protein supplements. Approved protein supplements consisted of 100% whey protein and minimal sugar and carbohydrate content to remain adherent to the intervention diet.

Additionally, both groups received instruction on how to properly complete a three-day Food Intake Record (FIR) as well as a weekly dietary checklist to monitor any excessive carbohydrate consumption. Participants also received reference handouts on form and technique for all the major power lifts as adapted by the International Powerlifting Federation Technical Rules Book[3] and instruction on how to properly fill out their weekly workout checklists.

Testing Procedures

Baseline data collection included 1-repetition max (1RM) assessment of all three major power lifts including bench press, squat and deadlift as validated by the National Strength and Conditioning Association. Participants also completed the first portion of the psychological assessment that included the completion of the HADS and POMS.

Psychological Testing Procedures

Hospital Anxiety and Depression Scale (HADS)

This instrument is ideal for monitoring anxiety and depression throughout any kind of treatment[19]. It accurately reflects and distinguishes changes in both anxiety and depression in response to emotional or physiological stress or change with results falling under normal, mild, moderate and severe[19]. The HADS has been validated across varying populations and interventions[19]. The HADS was administered three times at the beginning, midpoint and end of the six-week intervention period and was completed electronically via Qualtrics online survey (Qualtrics, Provos, UT) by each participant.

Profile of Mood States (POMS)

This is a validated self-report measure effective in quick assessment of fluctuating feelings and mood states applicable in a variety of settings including research and athletic settings[16]. It is composed of seven scales that combine to give a Total Mood Disturbance (TMD) score[16]. These scales are anger-hostility, confusion-bewilderment, depression-dejection, fatigue-inertia, tension-anxiety, vigor-activity and friendliness[16]. TMD scores range from -32 to 200 with lower scores indicative of more stable individuals and higher scores indicative of less stability and distress[16]. The POMS was administered approximately six times via Qualtrics online survey tool (Qualtrics, Provos, UT) to assess psychological fluctuation of participants over the course of the intervention period.

Strength Training Protocol

Each participant was required to participate in four training sessions per week, for six weeks. The training protocol used was previously validated by Crewther, Heke, Keough and published in *The Journal of Sports Medicine and Physical Fitness*[8]. Results

from the previous study show 11% gains in bench press max and 13% gains in back squat and deadlift when adhering to the validated training protocol[8]. The validated protocol includes two workouts that are alternated each day. Participants were prohibited from engaging in excessive physical activity or any other structured training program during the study. Workout spreadsheets were filled out for each workout to ensure compliance with training. Participants were also instructed to attend one mandatory supervised training session with one of the researchers each week.

Dietary Protocol

The LCKD group was instructed to consume less than 7% of total daily calories from carbohydrate, 50% from fat, and 45% from protein. Carbohydrates were restricted to no more than 50g per day in order to ensure participants begin producing ketone bodies. The control group was instructed to maintain their diet as normal.

The dietary intervention lasted six-weeks. Dietary compliance was monitored by mandatory three-day self-recorded dietary FIRs that were turned in either electronically or directly to the researchers during the second and fifth weeks of the intervention. The FIRs were analyzed using Nutrition Data System for Research software (Minneapolis, MN). Participants were also instructed to turn in provided dietary compliance checklists each week to evaluate carbohydrate intake quantities either electronically or directly to the researchers. If participants began to experience negative psychological effects due to the dietary intervention, they were directed to seek assistance from the University's Counseling Center.

Statistical Analysis

Data was analyzed using the SPSS 21.0 statistical software package (SPSS Inc., Chicago, IL). Descriptives were used to establish mean and +/-SD. Multivariate testing and general linear modeling were used to analyze the psychological scales, as well as t-tests for analysis within groups to determine if there was any significant change either between individuals or groups over the duration of the intervention. Statistical significance was determined using an alpha level of ($p < 0.05$). Data was also analyzed to determine whether or not depression-like symptoms contributed to the overall success of the intervention by comparing psychological scores both between and among groups.

RESULTS

Thirty-four participants were initially selected to be randomized into either the LCKD or CON group. Of those 34, 30 participants were randomized with 17 participants in the control group and 13 in the LCKD group with no significant statistical differences or covariates among groups evident (Table 1).

Sixteen participants, six from the LCKD group and 10 from control group, completed all three HADS administrations. Six participants, three from the LCKD group and three from the control group, completed all six administrations of the POMS. Reasons for participant dropout or incompletion included failure to comply with testing administration procedures, failure to adhere to dietary protocols, scheduling conflicts and unrelated illness resulting in study withdrawal.

Statistical analysis of the HADS psychological survey indicated that approximately 46.2% of the LCKD group and approximately 58.8% of the CON group

were compliant with testing procedures, indicating that all psychological assessments were completed correctly. General linear modeling and multivariate testing of anxiety responses both revealed that there was a significant decrease in anxiety over time both when combing groups ($p = 0.002$) and among CON group testing scores ($p = 0.008$) over the time duration of the study (Figure 1). Paired samples t-tests revealed significant differences between pre- and mid-testing (6.25 ± 2.77, 4.69 ± 1.99, $p = 0.018$) and pre- and post-testing (6.25 ± 2.77, 4.44 ± 2.45, $p = 0.009$) for combined groups HADS anxiety scale scoring. Paired samples t-tests also revealed a significant decrease in anxiety within the CON group between pre- and mid-testing (5.40 ± 1.90, 4.10 ± 1.85, $p = 0.022$) and pre- and post-testingf (5.40 ± 1.90, 4.00 ± 2.62, $p = 0.039$). Depression testing responses revealed no significant differences ($p > 0.05$) among or between either group over the duration of the study.

Statistical analysis of the POMS psychological survey indicated that approximately 23.1% of the LCKD group ($n = 3$) and approximately 17.6% of the CON group ($n = 3$) were compliant with testing procedures (Table 2). General linear modeling revealed no significant findings between the groups ($p > 0.05$) and multivariate testing was unable to effectively analyze responses or detect any significant trends week to week due to a small reporting sample size. Participant dropout and failure to comply with testing procedures over the course of the intervention most likely explain this.

Eleven participants completed the 1RM testing, four from the LCKD group and 7 from the CON group. This indicates that approximately 30.7% of the LCKD and approximately 41.2% of the CON group were compliant with 1RM testing procedures, indicating they completed both the pre- and post-testing sessions, as well includes one

participant who was unable to complete the bench press post-testing due to injury. Multivariate statistical testing revealed that there was not a significant difference ($p > 0.05$) in performance between the groups over the duration of the six-week intervention period. However, participant dropout throughout the intervention resulting in diminished sample size likely influenced these outcomes.

Individual t-tests revealed that both the LCKD and control group experienced a significant increase ($p < 0.05$) in 1RM for all three major lifts tested. Within the LCKD group, the deadlift was found to have a significant increase (18.18 ± 0.05 kg), as well as in the CON group (19.04 ± 11.77 kg)(Table 3). Within the CON group, both the bench press and back squat showed significant mean increase (6.80 ±4.52 kg, 16.48 ± 8.03, respectively) while the LCKD did not exhibit significant mean increases in these lifts.

Initial three-day FIR analysis found that all subjects consumed an average of 2,809 kilocalories per day with approximately 44% coming from carbohydrates, 35% coming from fats and the remaining 21% coming from protein. While all participants did not adhere to dietary protocols for the duration of the study, FIR's indicate at the midway point the LCKD group were consuming approximately 2,132 kilocalories per day with approximately 48% coming from fats, 23% coming from carbohydrates and the remaining 29% coming from protein. Post-testing FIR's also indicate that the LCKD group reduced total caloric intake to approximately 1,063 kilocalories per day with approximately 61% coming from fats, 31% from protein and 8% coming from carbohydrate sources (Table 4).

DISCUSSION

The aim of the present research was to determine the effects of a six-week LCKD combined with a strength training powerlifting protocol on performance and the associated psychological response. The principle findings of this study revealed that deadlift powerlifting performance can improve while on a strict LCKD dietary protocol adherence along with a significant decrease in anxiety has been shown to exist as a positive psychological response indicating a decrease in the depression-like symptom of anxiety among both the LCKD and CON groups. Additionally, this research did not exhibit any negative psychological responses to training or dietary protocol, as seen in previous literature.

As previously mentioned, limited research regarding a psychological response to carbohydrate-restricted dietary interventions and an associated training protocol exists to date[2,4]. Those that have included a psychological component found mixed results indicating both positive and negative psychological responses, making it difficult to generalize findings across varying populations[6,7,10,20-21]. Furthermore, studies that have demonstrated positive psychological responses to carbohydrate-restricted interventions combined with training lack sufficient evidence and explanation as to why such findings may be present for a given population[6,20-22]. Conversely, negative psychological responses, while somewhat more prevalent in the literature, also remain inconsistent in determining a generalizable response to such protocols[5-7].

Similar to the current study, a recent study conducted in 2006 by Degoutte et al. sought to determine both the physiological and psychological response to alternative training and preparation methods of competitive judo athletes[10]. While not explicitly prescribed to a LCKD, severe carbohydrate restriction was utilized by study participants

in preparation for simulated competition over the course of seven days[10]. While participants did report increased levels of fatigue after competition, the research revealed that there was no statistical significance of any depression-like symptoms as a result of dietary adherence and training protocol prior to or after competition[10].

Other long-term LCKD studies have also shown similar positive psychological responses to intervention training concurrent with the present study[11,20]. In 2009, Galletly et al. was able to demonstrate over 12-week period a reduction in such depression-like symptoms as diminished self-esteem, emotional eating and general feelings of depression, as well as metabolic improvements in participants adhering to a LCKD and exercise protocol[11]. Such findings may suggest LCKD's and concomitant exercise programs may not be responsible for resultant negative psychological responses, but rather contribute to a reduction of depression and depression-like symptoms as seen with anxiety in the present research.

Still, in the limited research available, other studies utilizing carbohydrate-restricted diets did demonstrate such negative psychological responses as irritability, decreased self-esteem, increased levels of fatigue and other physical symptoms, all of which may contribute to depression[6,7,14,17]. However, while the present study was not able to demonstrate a statistical significance between groups regarding performance, it was able to demonstrate individual increases in specific powerlifting exercises, suggesting that LCKD adherence does not diminish physical performance.

The current study demonstrated that macronutrient restriction led to an overall decrease in caloric intake. Contrary to some findings suggesting that this intake will not be compensated for by the remaining macronutrients, FIR analysis revealed an increase

in both fat and protein intake as the study progressed[17]. These findings are concurrent with other literature indicating that LCKD's lead to increased feelings of satiety and reduce the need to find comfort in food, which may lead to weight gain and an increase in depression-like symptoms[5,6,20-22].

The present research was able to improve upon many gaps evident in past studies, most notably the direct evaluation of a psychological response as it pertains to LCKD adherence combined with a validated powerlifting strength training protocol. The six-week time period also allows the psychological response to be effectively monitored throughout the duration of the intervention, as well as serve as an adequate length of time for metabolic change to occur.

Despite these improvements in research design, several limitations still exist that effect the generalizability of these findings. Most notably, statistical findings were greatly influenced by participant dropout and failing to adhere to all psychological testing procedures and may still indicate mixed results as it relates to a resultant positive psychological response. This also suggests that the trained, college-age, male population may not be the most appropriate population of evaluation. Additionally, the majority of the data was self-reported by the participants, which may also effect the generalizability of the current findings.

PRACTICAL APPLICATIONS

The current findings suggest that long-term adherence to a LCKD in combination with training may be an effective alternative preparation method for athletes in weight-class oriented sports as it demonstrated no significant detriment to performance.

Additionally, the psychological component of evaluation was able to demonstrate a significant decrease in anxiety among participants suggesting that this method of preparation can contribute to a resultant positive psychological response and reduction of anxiety, a depression-like symptom in athletes. This was particularly evident in one subject in the LCKD group who was compliant with all testing parameters of the current study. This participant exhibited a decrease in overall caloric intake, specifically carbohydrate intake as low as 8% in the final FIR and produced urinary ketones throughout the study. He also showed a decrease in anxiety in HADS anxiety scores between the initial and final testing, as well as no significant increase POMS TMD score. Still, further research is warranted focusing on sport-specific populations to determine whether or not LCKD's are an effective alternative method of competition preparation.

TABLES

Table 1 – Baseline demographical data for male college students on either an ad libitum or low carbohydrate ketogenic diet

	LCKD	**CON**
Age	19.23 +/- 1.2	20.67 +/- 1.8
BMI (kg/m^2)	26.70 +/- 2.9	25.76 +/- 2.3
Height (cm)	177.80 +/- 7.36	178.96 +/- 6.13
Weight (kg)	85.58 +/- 15.5	81.54 +/- 9.6
Fat (%)	17.98 +/- 6.8	14.10 +/- 4.3
Fat Mass (kg)	14.68 +/- 7.2	11.23 +/- 4.1
Fat Free Mass (kg)	68.46 +/- 9.4	70.98 +/- 7.4

Numbers represented as mean +/- SD

Table 2 – Profile of Mood States (POMS) statistical analysis output of Total Mood Disturbance (TMD) scores for male college athletes on an ad libitum or low carbohydrate ketogenic diet over six weeks

	TMD Score 1	**TMD Score 2**	**TMD Score 3**	**TMD Score 4**	**TMD Score 5**	**TMD Score 6**
LCKD	80.33 ± 17.47	79.00 ± 38.97	93.33 ± 48.44	64.67 ± 21.94	61.67 ± 50.86	55.00 ± 14.80
CON	64.67 ± 49.69	59.33 ± 16.17	63.33 ± 25.54	61.00 ± 15.39	95.33 ± 34.21	58.00 ± 15.13
Total	72.50 ± 34.40	69.17 ± 28.78	78.33 ± 38.33	62.83 ± 17.70	78.50 ± 42.93	56.50 ± 13.49

*No statistically significant ($p < 0.05$) values for POMS TMD scores were exhibited between either individuals or group over the six-week intervention.
Numbers represented as mean +/- SD

Table 3 – Pre and post intervention one repetition max (1RM) for bench press, back squat and deadlift for male college students on either an ad libitum or low carbohydrate ketogenic diet

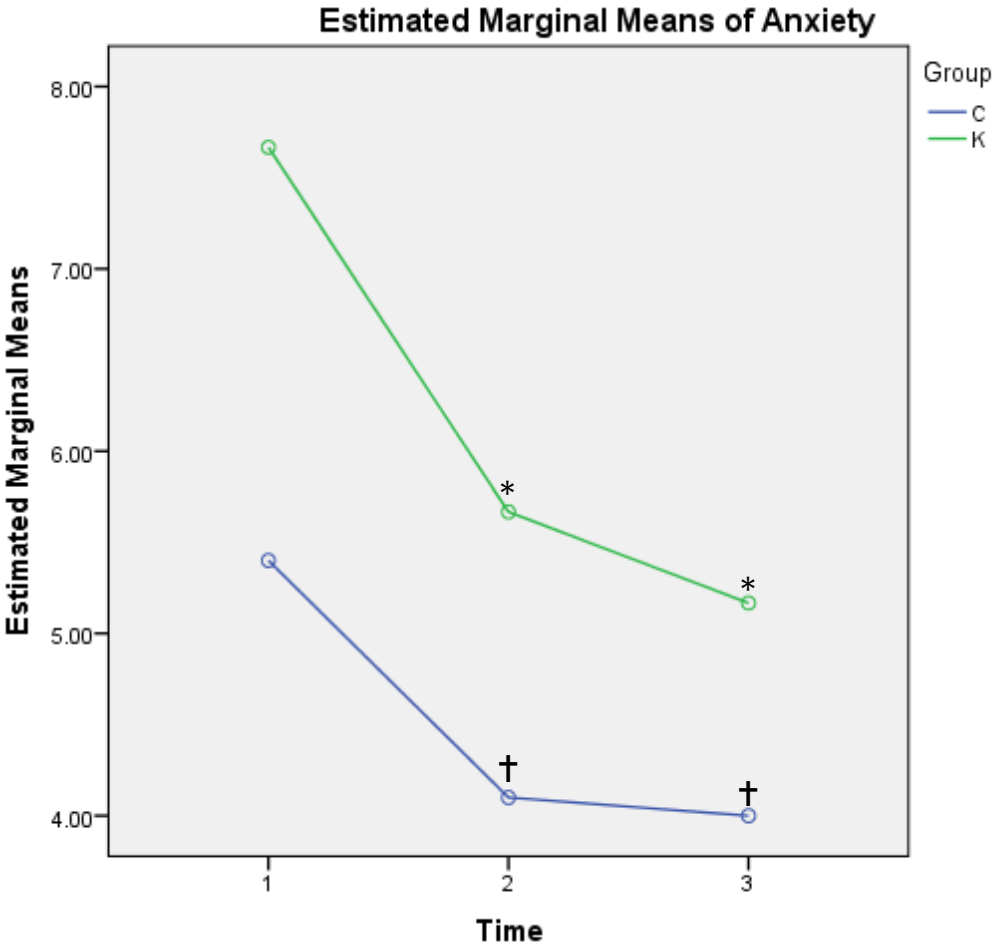
	LCKD			**CON**		
	Pre	**Post**	**Change**	**Pre**	**Post**	**Change**
Bench Press (kg)	85.8 ± 8.79	93.2 ± 13.39	7.38 ± 5.99	106.5 ± 17.24	113.3 ± 14.39*	6.80 ± 4.52
Back Squat (kg)	109.7 ± 18.86	119.3 ± 20.79	9.68 ± 11.79	134.7 ± 17.08	151.1 ± 14.54*	16.48 ± 8.03
Deadlift (kg)	119.3 ± 16.34	137.5 ± 16.36*	18.18 ± 0.05	143.8 ± 13.64	162.8 ± 18.07*	19.04 ± 11.77

*Significant increase ($p < 0.05$) in 1RM change within each group
Number represented as mean ± SD

Table 4 – Mean descriptive statistical analysis of Food Intake Records for male college students adhering to either an ad libitum diet or low carbohydrate ketogenic diet

	Baseline (all subjects combined)	**LCKD Week 2-4**	**CON Week 2-4**	**LCKD Week 5-6**	**CON week 5-6**
Total Kcal	2809	2132	2893	1063	2831
CHO (g)	311.3	127.7	269.7	24.4	265.6
PRO (g)	121.9	149.8	168.7	78.5	163.0
FAT (g)	110.8	114.4	116.7	72.3	124.4

Figure 1 – Hospital Anxiety and Depression Scale calculated scores of anxiety of college males on an ad libitum or low carbohydrate ketogenic diet over a six-week intervention period



*Significant decrease between pre-post and pre- mid ($p<0.05$) for combined group anxiety scores
†Significant decrease between pre-post and pre-mid ($p< 0.05$) for ad libitum group

Appendices

Appendix A

1-Repetition Max Testing Protocol[3]

1-RM TESTING PROTOCOL

1. Instruct the athlete to warm up with a light resistance that easily allows 5-10 repetitions.
2. Provide a 1-min rest period.
3. Estimate a warm-up load that will allow the athlete to complete 3-5 repetitions by adding
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
4. Provide a 2-min rest period.
5. Estimate a conservative, near-maximum load that will allow the athlete to complete 2-3 repetitions by adding
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
6. Provide a 2-4-min rest period.
7. Make a load increase
   - 10-20lb (4-9kg) or 5-10% for upper-body exercise or
   - 30-40lb (14-18kg) or 10-20% for lower-body exercise
8. Instruct the athlete to attempt a 1-RM.
9. If the athlete was successful, provide a 2-4-min rest period and go back to step 7.

If the athlete failed, provide a 2-4-min rest period, decrease the load by subtracting

- 5-10lb (2-4kg) or 2.5-5% for upper-body exercises or
- 15-20lb (7-9kg) or 5-10% for lower-body exercises

AND then go back to step 8.

Continue increasing or decreasing the load until the athlete can complete one repetition with proper exercise technique. Ideally the athlete's 1-RM will be measured within 5 testing sets.

Appendix B

Six-Week Strength Training Protocol

TABLE II.—*Exercises and loading protocols for the resistance-training program.*

Day One	Day Two	Week 1	Week 2	Week 3
		†50, 70, 80, 80% 1RM	†50, 70, 80, 85% 1RM	†50, 75, 80, 90% 1RM
Squats	Deadlifts	*4 x 12, 8, 6, 6	*4 x 12, 8, 6, 4	*4 x 12, 8, 5, 2
Bench press	Military press	*4 x 12, 8, 6, 6	*4 x 12, 8, 6, 4	*4 x 12, 8, 5, 2
Leg curls	Pull-downs	*4 x 12, 8, 6, 6	*4 x 12, 8, 6, 4	*4 x 12, 8, 5, 2
DB chest flies	Close grip bench	3 x 8 RM	3 x 10 RM	3 x 12 RM
Calf raises	Barbell Bicep curls	3 x 8 RM	3 x 10 RM	3 x 12 RM
Bar dips	Shrugs	3 x 8 RM	3 x 10 RM	3 x 12 RM
Day One	Day Two	Week 5	Week 6	Week 7
		†55, 75, 85, 85, 92% 1RM	†55, 75, 85, 90% 1RM	†60, 75, 85, 90, 94% 1RM
Squats	Deadlifts	*5 x 12, 8, 4, 3, 3	*4 x 12, 8, 4, 1-3	*5 x 12, 6-8, 5, 4-6, 1-3
Bench press	Military press	*5 x 12, 8, 4, 3, 3	*4 x 12, 8, 4, 1-3	*5 x 12, 6-8, 5, 4-6, 1-3
Leg curls	Pull-downs	*5 x 12, 8, 4, 3, 3	*4 x 12, 8, 4, 1-3	*5 x 12, 6-8, 5, 4-6, 1-3
DB Chest flies	Close grip bench	3 x 8 RM	3 x 10 RM	3 x 12 RM
Calf raises	Barbell Bicep curls	3 x 8 RM	3 x 10 RM	3 x 12 RM
Bar dips	Shrugs	3 x 8 RM	3 x 10 RM	3 x 12 RM

RM: repetition maximum. †Training intensity and *Sets x repetitions for the first three exercises.

Appendix C

Hospital Anxiety and Depression Scale

Question	**Responses**	**Points**
I feel tense or 'wound up':	Most of the time A lot of the time From time to time, occasionally Not at all	3 2 1 0
I still enjoy the things I used to enjoy:	Definitely as much Not quiet so much Only a little Hardly at all	0 1 2 3
I get a sort of frightened feeling as if something awful is about to happen:	Very definitely and quiet badly Yes, but not too badly A little, but it doesn't worry me Not at all	3 2 1 0
I can laugh and see the funny side of things:	As much as I always could Not quite so much now Definitely not so much now Not at all	0 1 2 3
Worrying thoughts go through my mind:	A qreat deal of the time A lot of the time From time to time but not too often Only occasionally	3 2 1 0
I feel cheerful:	Not at all Not often Sometimes Most of the time	3 2 1 0
I can sit at ease and feel relaxed:	Definitely Usually Not often Not at all	0 1 2 3

I feel as if I am slowed down:	Nearly all the time Very often Sometimes Not at all	3 2 1 0
I get a sort of frightened feeling like 'butterflies' in the stomach:	Not at all Occasionally Quite often Very often	0 1 2 3
I have lost interest in my appearance:	Definitely I don't take so much care as I should I may not take quiet as much care I take just as much care as ever	3 2 1 0
I feel restless as if I have to be on the move:	Very much indeed Quite a lot Not very much Not at all	0 1 2 3
I look forward with enjoyment to things:	As much as ever I did Rather less than I used to Definitely less than I used to Hardly at all	0 1 2 3
I get sudden feelings of panic	Very often indeed Quite often Not very often Not at all	3 2 1 0
I can enjoy a good book or radio or TV program	Often Sometimes Not often Very seldom	0 1 2 3
TOTAL SCORE		

Appendix D

Borg Rating of Perceived Exertion Scale (RPE)

6 – No exertion at all

7

(7.5) – Extremely light

8

9 – Very light

10

11 – Light

12

13 – Somewhat hard

14

15 – Hard (heavy)

16

17 – Very hard

18

19 – Extremely hard

20 – Maximal exertion

Appendix E

Profile of Mood States

FEELING	Not at All	A Little	Moderate	Quite a Bit	Extremely
1. Friendly	1	2	3	4	5
2. Tense	1	2	3	4	5
3. Angry	1	2	3	4	5
4. Worn Out	1	2	3	4	5
5. Unhappy	1	2	3	4	5
6. Clear-headed	1	2	3	4	5
7. Lively	1	2	3	4	5
8. Confused	1	2	3	4	5
9. Sorry for things done	1	2	3	4	5
10. Shaky	1	2	3	4	5
11. Listless	1	2	3	4	5
12. Peeved	1	2	3	4	5
13. Considerate	1	2	3	4	5
14. Sad	1	2	3	4	5
15. Active	1	2	3	4	5
16. On Edge	1	2	3	4	5
17. Grouchy	1	2	3	4	5
18. Blue	1	2	3	4	5
19. Energetic	1	2	3	4	5
20. Panicky	1	2	3	4	5
21. Hopeless	1	2	3	4	5
22. Relaxed	1	2	3	4	5
23. Unworthy	1	2	3	4	5
24. Spiteful	1	2	3	4	5
25. Sympathetic	1	2	3	4	5
26. Uneasy	1	2	3	4	5
27. Restless	1	2	3	4	5
28. Unable to	1	2	3	4	5
29. Fatigued	1	2	3	4	5
30. Helpful	1	2	3	4	5
31. Annoyed	1	2	3	4	5

32. Discouraged	1	2	3	4	5
33. Resentful	1	2	3	4	5
34. Nervous	1	2	3	4	5
35. Lonely	1	2	3	4	5
36. Miserable	1	2	3	4	5
37. Muddled	1	2	3	4	5
38. Cheerful	1	2	3	4	5
39. Bitter	1	2	3	4	5
40. Exhausted	1	2	3	4	5
41. Anxious	1	2	3	4	5
42. Ready to fight	1	2	3	4	5
43. Good-natured	1	2	3	4	5
44. Gloomy	1	2	3	4	5
45. Desperate	1	2	3	4	5
46. Sluggish	1	2	3	4	5
47. Rebellious	1	2	3	4	5
48. Helpless	1	2	3	4	5
49. Weary	1	2	3	4	5
50. Bewildered	1	2	3	4	5
51. Alert	1	2	3	4	5
52. Deceived	1	2	3	4	5
53. Furious	1	2	3	4	5
54. Effacious	1	2	3	4	5
55. Trusting	1	2	3	4	5
56. Full of pep	1	2	3	4	5

57. Bad-tempered	1	2	3	4	5
58. Worthless	1	2	3	4	5
59. Forgetful	1	2	3	4	5
60. Carefree	1	2	3	4	5
61. Terrified	1	2	3	4	5
62. Guilty	1	2	3	4	5
63. Vigorous	1	2	3	4	5
64. Uncertain about things	1	2	3	4	5
65. Bushed	1	2	3	4	5

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