The University of Western Australia

PREDICTING MENTAL IMAGERY CONCRETENESS

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1 Abstract

The COVID-19 pandemic has forced a sudden change in society that we weren't fully prepared for. Self-isolation and physical distancing has been imposed on everyone in varying degrees and the effect of it on people's mental wellbeing is an area of interest, especially if a second or third wave of the pandemic will require people to undergo isolation again. Certain members of the community are going to be affected more than others from this rapid disruption of the day-to-day because they are not getting the usual levels of social interaction they need or are used to to maintain a healthy mental wellbeing. It is in our interest to find which members of our community are at most risk with a method that is highly accessible given the physical restrictions that such a societal condition imposes.

Mental imagery, the simulation of perceptual experience across sensory modalities, has been strongly linked to depression. It is one avenue that we may attempt to examine a person on to see if they are at risk of suffering from loneliness. Inference and prediction of a person's quality of mental imagery, particularly concreteness, is the focus of this research. Classical techniques and natural language processing techniques have been employed to generate a series of models to understand mental imagery concreteness.

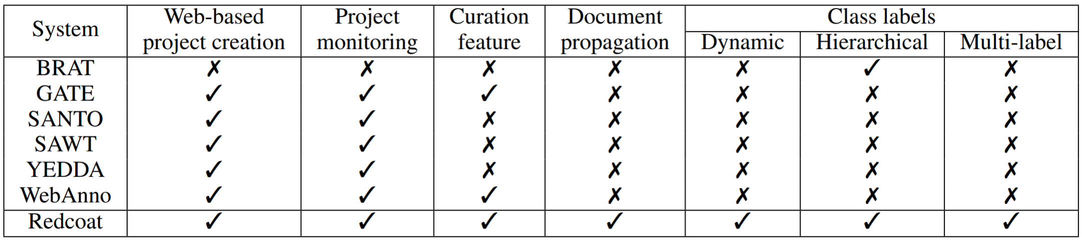
2 Review of Literature

2.1 Mental Imagery

Mental imagery is the simulation of perceptual experience [11] across sensory modalities. It has been strongly linked to depression [14] which is our main area of interest. As detailed in Kosslyn et al's 2001 paper, the current techniques for measurements of a person's mental imagery involve visual tests, classification tasks, comparison tasks, questionnaires and interviews.

The usage of machine learning and natural language processing has not yet been deeply explored in extracting mental imagery parameters, though theoretically, it would be most similar to the existing method of using interviews and analyzing a person's speech and selection of words to derive the wanted parameters, except with machine learning, the assessment would be automated rather than needing a trained professional to go through each case individually, which would be an expensive process that won't be easily scalable in an isolation scenario where potentially a huge percentage of people are affected.

Dr. Julie Ji's research on mental imagery, the experience of perception in the absence of external sensory input, shows that the person's quality of mental imagery-based simulations has a significant link to maintaining and amplifying emotional states [9]. In one study on mental imagery as a motivational amplifier to promote activities as a key treatment in depression [16], the Motivational Imagery group reported higher levels of motivation, anticipated pleasure, and anticipated reward for the planned activities compared to the Activity Reminder control group and the No-Reminder



System	Web-based project creation	Project monitoring	Curation feature	Document propagation	Class labels		
					Dynamic	Hierarchical	Multi-label
BRAT	✗	✗	✗	✗	✗	✓	✗
GATE	✓	✓	✓	✗	✗	✗	✗
SANTO	✓	✓	✗	✗	✗	✗	✗
SAWT	✓	✓	✗	✗	✗	✗	✗
YEDDA	✓	✓	✗	✗	✗	✗	✗
WebAnno	✓	✓	✓	✗	✗	✗	✗
Redcoat	✓	✓	✓	✓	✓	✓	✓

Figure 1: Annotation tools comparison

control group.

2.2 Named Entity Recognition

We aim to be able to utilise the free-text responses of the survey to create a model that performs better than a regression model from the human-graded mental imagery parameters that predicts a person's risk of loneliness. To achieve this, the collected free-text responses have to be annotated with respect to the domain of interest. In our particular research area, it will be important to tag self actions (meditate, jog, sleep in, watch TV, etc) and interpersonal actions (call friend, video call with parents, have dinner at restaurant with partner) separately, which most pre-trained models aren't trained to do. Due to this, and also because we have a relatively small sample size, we have the luxury of using manual annotation to improve our data's richness and context.

In the paper Multilingual Twitter Sentiment Classification: The Role of Human Annotators by Mozetic et al, [13], they find that the quality of classification models depends much more on the quality and size of training data than on the type of model trained. Human annotators can help us maximise our model's performance by ensuring good annotation quality, which can be done by setting an overlap value (the number of times a single corpus is annotated) of at least 2.

There are a lot of tools for data annotation available. Among these options are BRAT, GATE Teamware, WebAnno, SAWT, Yedda, SANTO and UWA's Redcoat. We can see a comparison of their features in Figure 1. With research assistants to help out with our data as annotators, an important feature we are looking for in an annotating tool is the ability to propagate documents easily and for the tool to scale the workload automatically based on the number of annotators. Redcoat [18] has been selected as the annotating tool for that reason, alongside being web-based and easy to set up and distribute.

2.3 Sentiment Analysis

One of the mental imagery parameters we're concerned with is a person's emotional tone when they're describing what they think or see when they're given a scenario and a goal of starting lonely in an isolated setting and ending in a brighter, happier mental state. A person's emotional tone can be approximated with sentiment analysis techniques. XLNet has been used to identify optimism and pessimism in twitter messages by Alshahrani et al [3], which is similar to what we're trying to achieve. XLNet models are able to model negations and other semantic relationships by paying attention to key words, leading to a model accuracy of 0.9645.

A point of discussion would be if our research problem would work better with basic sentiment analysis or aspect-based sentiment analysis. Normal sentiment analysis grades the emotional tone of the overall text, while aspect-based sentiment analysis goes through the text to identify various aspects and determines the corresponding emotional tone for each one. There isn't much available literature on when each of the techniques are relevant or when each of them should be used over the other, but the spirit of parsimony would lead us to towards using aspect-based sentiment analysis only if there are particular aspects in our research domain that we want to track individually.

For the lack of literature on comparison between the two techniques on different domains, there is merit in trying both individually, or creating a model that uses both techniques in tandem and empirically comparing which technique works best for our research problem.

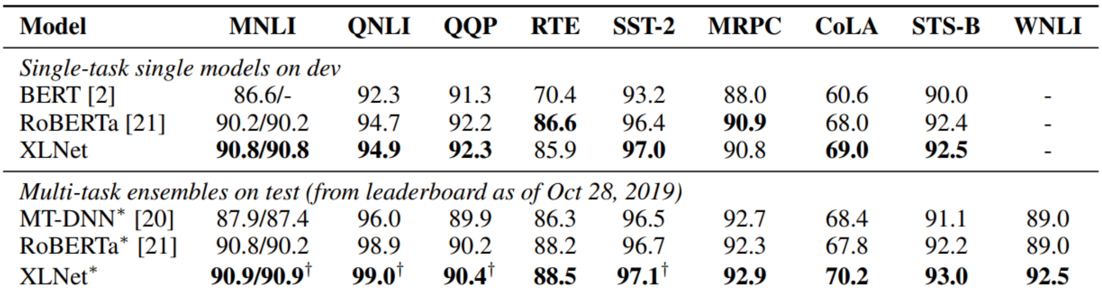
2.4 Transfer Learning

Language is complex. In order to get reasonably performing models from scratch, one would need an extremely large dataset in addition to the computing power needed to process it. This is often impossible for many researchers, and a solution to this problem is transfer learning. Transfer learning is a machine learning technique where a model is trained on a particular problem, then reused in a similar domain to carry over the knowledge of the neural network. Depending on how different the pre-trained model is to your problem, Additional training needs to be done to finetune the model to your specific domain. [17]

Popular pre-trained NLP models include Google's BERT, Google and Carnegie Mellon University's XLNet, and Facebook's RoBERTa. All of these models are transformers which are deep learning models designed to handle sequential data using the concept of attention mechanisms. Attention mechanisms allow the model to access and use any previous states and utilises them based on relevance to the current node. [19]

In particular, we want a pretrained model that is strong in sentiment analysis. Looking at Figure 2 in the SST-2 column which stands for the Stanford Sentiment Treebank v2, we can see that XLNet [20] outperforms both BERT and RoBERTa in sentiment analysis on the SST-2 dataset.

While XLNet, BERT and RoBERTa all come from the same family of models, XLNet differs by introducing permutation language modelling, where all tokens are predicted in a random, permutated order rather than the traditional sequential order. This helps XLNet learn non-adjacent and bidirectional relationships between the words in the corpus. Secondly, XLNet uses Transformer-XLs as the base architecture which enables learning dependency beyond a fixed length without disrupting



Model	MNLI	QNLI	QQP	RTE	SST-2	MRPC	CoLA	STS-B	WNLI
Single-task single models on dev									
BERT [2]	86.6/-	92.3	91.3	70.4	93.2	88.0	60.6	90.0	-
RoBERTa [21]	90.2/90.2	94.7	92.2	**86.6**	96.4	**90.9**	68.0	92.4	-
XLNet	**90.8/90.8**	**94.9**	**92.3**	85.9	**97.0**	90.8	**69.0**	**92.5**	-
Multi-task ensembles on test (from leaderboard as of Oct 28, 2019)									
MT-DNN* [20]	87.9/87.4	96.0	89.9	86.3	96.5	92.7	68.4	91.1	89.0
RoBERTa* [21]	90.8/90.2	98.9	90.2	88.2	96.7	92.3	67.8	92.2	89.0
XLNet*	**90.9/90.9**†	**99.0**†	**90.4**†	**88.5**	**97.1**†	**92.9**	**70.2**	**93.0**	**92.5**

Figure 2: Pre-trained NLP models results on GLUE

temporal coherence. [5] Transformer-XLs, even without the permutation language modelling, has been shown to give performance increases in NLP tasks.

While the performance benchmarks above in Figure 2 suggest that XLNet would perform the best, the hardware available for use for this research lacks the capability to run a heavyweight transformer model. For this reason, RoBERTa [12], coming as a close second, shall be used in this study as choice of pretrained transformer model.

3 Data

3.1 Core dataset

The core dataset for this study is a conglomerate of surveys from volunteers (n=1269) including a baseline day zero survey, daily surveys, and weekly checkpoints up to the fourteenth day. The baseline survey asked for the volunteers' mental health status, education, employment, age, coinhabitant count, isolation experience, the Hospital Anxiety and Depression Scale (HADS) scores, and other miscellaneous information. A loneliness score and social activity score have been assigned to each volunteer based on their answers to the relevant questions. In addition, a text response to the below instruction was requested.

> The story begins with you feeling isolated and lonely.
>
> The story ends with you feeling connected and closer to people.
>
> Please come up with the steps you would take to achieve the story ending, providing as much detail as you can about your thoughts, feelings, and actions related to these problem-solving steps.

The responses are then manually rated by humans on four mental imagery parameters. Each response is assessed by two raters to improve reliability. The final score is calculated as the average of the two ratings. The four mental imagery parameters are as below:

- Number of relevant problem-solving steps: Discrete steps that helps the person to reach the desired goal or to overcome an obstacle along the way

- Solution Effectiveness: How much you think the described solution would maximise positive and minimise negative consequences in the short-term and long-term, both personally and socially
- Solution Concreteness: The degree to which the described solution reflects concrete plans, i.e. involving specific actions, times, places, and people
- Emotional Tone: The degree to which the participant sounds negative (downbeat/pessimistic/unsure) or positive (upbeat/optimistic/confident)

The daily surveys track the the volunteers' depression and anxiety levels, their Warwick-Edinburgh Mental Well-being Scale (WEMWBS) scores, physical activity levels, social activity levels, and if and how often they've been outside of their accommodation. The weekly surveys include the normal daily survey questions and adds HADS, loneliness, and optimism score assessments.

3.2 Word concreteness dataset

The paper *Predicting Word Concreteness and Imagery* [4] by Charbonnier and Wartena has outputted a dictionary of words and their concreteness ratings. These scores are obtained by training a regression model using precomputed word embeddings from GoogleNews and fastText, suffixes and the word's part of speech (POS) tag as the features and manually scored concreteness values as the target. The dataset contains 39955 unique singleton and bigram words.

3.3 Discretisation of Concreteness

Concreteness is recorded as a numerical number between 1 and 5 with half steps and some quarter steps in between due to the averaging done on the varying ratings on some of the observations. Given our dataset is small (n=1236, 1088 if you remove invalid responses), it is of interest to further decrease the number of bins for Concreteness. It will also help with the interpretation of the model, as in practice, we will be looking for people with generally low, medium or high concreteness values, not necessarily if they have a score of 1 or 1.5.

Three levels have been deemed important in the scope of this research: Low, Medium, and High. The cutoff points were chosen to minimise the relative class sizes, as if we were to trisect the number scale, we would end up with a high class imbalance particularly against High. See Figure 3 to see the raw concreteness distribution. Concreteness scores in the [0, 1.5) range are classed into Low, [1.5, 2.5) into Medium, and [2.5, 5] into High. While the number of observations falling under High Concreteness is still fairly lower than those in Low or Medium as can be seen in Figure 4, any other cutoff combination for our dataset would make further imbalance the classes. This is just the nature of our data where concreteness scores are concentrated in the lower ranges.

Aside from the three levels, we will also explore models focusing on a boolean classification of Low Concreteness or not.

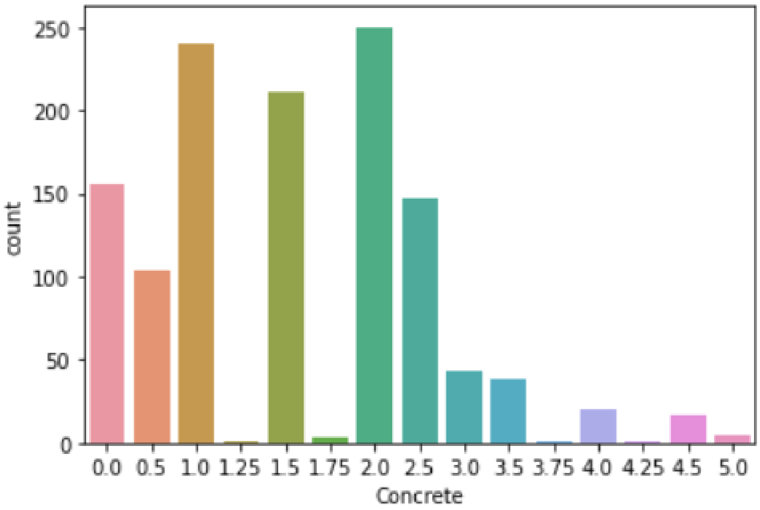


Figure 3: Concreteness histogram

4 Methodology

4.1 Inferential analysis

The goal for this section is to discover key features in the data that can be easy identifiers for concreteness without resorting to unexplainable prediction models. It would be valuable to know particular features of low and high concreteness individuals as it may give us a better understanding on the subject matter.

4.1.1 Baseline model

The baseline model will be a predictor model for concreteness from non-textual information available from a candidate at day zero. Information such as loneliness and social activity scores available at future days will not be accessible to this model. Its purpose is to find out how accurate we can get our predictions to be of concreteness given a person's own profile, demographic, and self-assessment alone. The full list of parameters used for this baseline model is itemised below:

- Demographical information: age, gender, education, employment, and working from home status
- Self-rated assessments of mental imagery in terms of actions, people, emotions, and vividness
- Number and type of cohabitants, including pets
- HADS scores for depression and anxiety calculated through a series of questions
- Number of days practicing social distancing to date

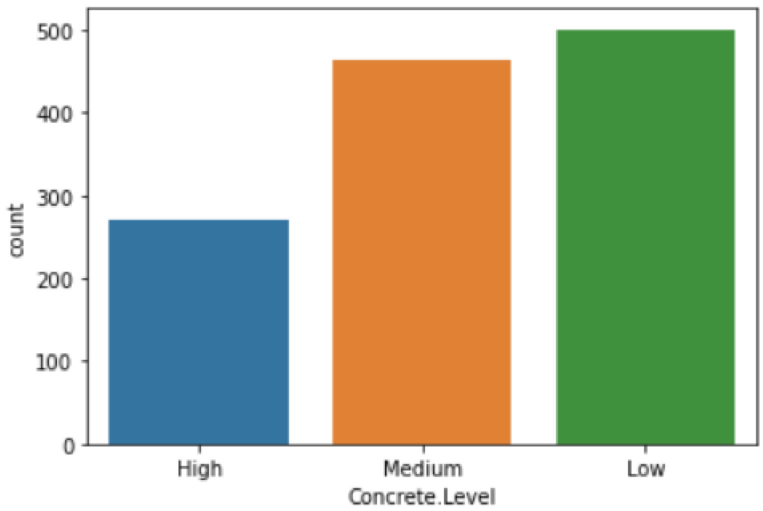


Figure 4: Discretised Concreteness histogram

- Perceived risk of loneliness, worry, stress, family conflict, inactivity and listlessness
- If any current or past mental health diagnoses exist

Stepwise selection will be used to narrow down the predictive parameters to only the most significant few to maximise the AIC score of the model. Multiple linear regression will be the regression technique of choice in order to better understand the effect of each significant variable on concreteness as compared to less inferential techniques such as support vector machines.

4.1.2 Word-level mined variables

Word-level approaches will be applied to the response texts to gather high level information to see if using the response text can bring an improvement in performance to our Concreteness prediction model. The word concreteness dictionary from Charbonnier's *Predicting Word Concreteness and Imagery* paper [4] will primarily be utilised to gather new features from the responses in our observations. Bigrams will also be included in the data mining.These new features will be a good preliminary indicator on if more complex natural language processing techniques will yield a better understanding of concreteness in terms of prediction.

Multiple linear regression will be used similar to the baseline model, with the difference being the addition of new data on word concreteness. Stepwise selection will be used to narrow down the predictive parameters, with the new fields being added to the model afterwards if not already selected by the algorithm.

4.1.3 One-vs-rest Classification

The discretisation of Concreteness will allow us to use the One-vs-rest logistic classification. Three individual models will be created for predicting if an observation is of Low, Medium, or High Concreteness. This will also make it possible to see if different factors count for different Concreteness levels which may come useful for inference of what variables to look out for for specific classes.

Stratified sampling will be done for the train test split as it is important to make sure that each class is relatively equally represented given the slight imbalance in class sizes.

4.1.4 Decision Tree

Decision Trees are highly explainable classification models which could give us heuristics for classifying a person's level of Concreteness. We will be using Conditional Inference Trees [7] using the ctree command from the party package in R.

4.2 Prediction with natural language processing techniques

The primary approach to be investigated in this study is the usage of natural language processing techniques to predict concreteness and comparing its performance compared to classical non-NLP approaches. The two main architectures to be explored are bidirectional LSTMs [8] and pretrained transformer models, particularly RoBERTa [12] as they are the two architecture types that have stayed at the forefront of advancement in the field of NLP.

Both of these models will be used for binary (Low and not low) and multilevel (Low, Medium, High) classification.

4.3 Prediction with classical techniques

While we will have an early attempt at prediction during the inferential analysis part of the study, there are techniques much better suited to our goal of prediction accuracy. The classics approaches that are strong and popular models for prediction to be used are SVMs and Random Forests.

Both of these models will be used for binary (Low and not low) and multilevel (Low, Medium, High) classification.

5 Results and Discussion

5.1 Inferential analysis

5.1.1 Baseline model

Using the stepwise algorithm for model selection on linear regression has yielded the following model:

Coefficient	Estimate	Standard Error	p-value
Intercept	0.7309	0.4178	0.0806
Perceived Risk (Listlessness)	-0.1065	0.0298	0.0004
Self-rated Mental Imagery Score (Action)	0.0798	0.0289	0.0058
Coinhabitants (Adult, Other)[1]	-0.1901	0.0798	0.0175
Mental Health Diagnosis (none)	0.8957	0.4099	0.0291
Mental Health Diagnosis (unsure)	1.2529	0.4995	0.0123
Mental Health Diagnosis (yes - current)	0.9820	0.4133	0.0177
Mental Health Diagnosis (yes - past)	0.0485	0.0314	0.1226
Self-rated Mental Imagery Score (Vividness)	0.0485	0.0314	0.1226

Table 1: Baseline Model

This baseline model has an adjusted R^2 score of 0.0400 which means that the variables selected account only for approximately 4% of the variance of Concreteness, which is abysmally low and unusable for prediction purposes. This low score can mean two possible things. First is that the relationship between the predictors and the target variable may not be linear in nature. Second is that the baseline variables may simply not be strongly related to a person's concreteness of mental imagery that is estimated by humans by assessing the response text.

5.1.2 Word-level mined variables

A series of new fields have been generated using the word concreteness dictionary from Charbonnier's *Predicting Word Concreteness and Imagery* paper [4]. Concreteness information from both individual words and bigrams have been mined. Raw counts and densities (raw count over total word count) were obtained for both high concreteness (defined by having a score of greater than three in an approximate five point scale) and extreme concreteness (defined by having a score of greater than four in an approximate five point scale) for individual words. Raw counts for high concreteness is the only metric obtained for bigrams as there are generally fewer tagged bigrams to score in the corpus. Raw word count has also been added.

Using the stepwise algorithm for model selection on linear regression has yielded the following model:

[1] Number of adult coinhabitants that are not your family, partner, or friend.

[2] Number of words that have concreteness values of three or above in an approximate five point scale.

Coefficient	Estimate	Standard Error	p-value
Intercept	1.5834	0.1033	< 2e-16
High Concreteness Word Count^2	0.0191	0.0050	0.0001
Perceived Risk (Listlessness)	-0.0865	0.0268	0.0013
Self-rated Mental Imagery Score (Vivid)	0.0552	0.0273	0.0435
Outside Activity Score	-0.0550	0.0330	0.0961
Word Count	-0.0016	0.0011	0.1534

Table 2: Word-level model

This word-level model has an adjusted R^2 score of 0.0774 which means that the variables selected account only for approximately 7.74% of the variance of Concreteness. This is considerably higher than the baseline model's adjusted R^2 score of 0.0400, but it is still inadequate for practical applications. It is valuable, however, to note that the contribution of word-level mined variables into the model nearly equals the effect of everything else in the model, which gives us further evidence to explore the text response of the observations using NLP techniques.

5.1.3 One-vs-rest Classification

A one-vs-rest classification approach has been applied to the data. This will also be useful to see if people with low levels of concreteness can be identified by different predictors to people with high levels of concreteness. A higher score in the individual models means that it is more likely that an observation belongs to the model's designated class.

Coefficient	Estimate	Standard Error	p-value
Intercept	-0.0874	0.2159	0.6856
High Concreteness Word Count	-0.0469	0.0078	1.77e-09
Perceived Risk (Listlessness)	0.1847	0.0739	0.0125

Table 3: Low Concreteness Model

5.1.3.1 Low Concreteness model The model parameters can be found in Table 3. The low concreteness model has yielded a training accuracy of 0.6758 and a test accuracy of 0.7200. This model is the simplest one we've encountered which is quite insightful. Both high concreteness word count and perceived risk of listlessness are consistently significant predictors for many of our models here, and the patterns are the same. More occurences of high concreteness words generally lead to high concreteness scores (hence the negative relationship between high concreteness word counts and the probability of being a low concreteness observation) and a higher perceived risk of listlessness generally leads to low concreteness scores.

5.1.3.2 Medium Concreteness model The model parameters can be found in Table 4. The medium concreteness model has yielded a training accuracy of

Coefficient	Estimate	Standard Error	p-value
Intercept	-1.0859	0.3971	0.0063
High Concreteness Bigram Count	-0.2209	0.1079	0.0407
Distancing Impact	0.0854	0.0512	0.0950
Isolation Days	-0.0145	0.0093	0.1216
Age Group (25-44)	0.5346	0.3739	0.1527
Age Group (45-64)	0.4569	0.3580	0.2019
Age Group (65-79)	0.9387	0.3858	0.0150
Age Group (80+)	1.3443	0.9836	0.1717
Physical Activity Score	0.0144	0.0094	0.1245

Table 4: Medium Concreteness Model

0.5710 and a test accuracy of 0.5086. This model is the worst performer of the one-vs-rest models, sitting just a small bit better than guessing if an observation counts as a medium concreteness observation or not. Luckily, predicting low and high concreteness observations are more important in practical applications.

Coefficient	Estimate	Standard Error	p-value
Intercept	-1.6622	0.3240	2.88e-07
High Concreteness Word Count	0.0601	0.0157	0.0001
Word Count	-0.0067	0.0034	0.0513
High Concreteness Bigram Count	0.2446	0.1242	0.0488
Perceived Risk (Listlessness)	-0.2000	0.0875	0.0223
Self-rated Mental Imagery Score (Scenes)	0.1394	0.0776	0.0723
Working From Home (No)	-0.6766	0.2724	0.0130
Working From Home (Yes, some work days)	-0.1932	0.3338	0.5626
Working From Home (Yes, all work days)	0.1008	0.2330	0.6652
Coinhabitants (Children)	0.1707	0.1019	0.0939
Distancing Impact	-0.1031	0.0659	0.1176

Table 5: High Concreteness Model

5.1.3.3 High Concreteness model The model parameters can be found in Table 5. The high concreteness model has yielded a training accuracy of 0.7762 and a test accuracy of 0.7771. From the relatively high accuracy scores, it seems like high concreteness observations are more easily predictable with our given variables. High concreteness word and bigram count appear as significant variables, with the negative estimate on word count working as a balancer to divide responses rich in high concreteness words as compared to responses that are just long. Perceived risk of listlessness is also present, staying consistent in its negative relationship to concreteness.

5.1.3.4 Concreteness Classifier A concreteness classifier that uses the outputs of the three individual models and selects the max has been created. A confusion matrix on the model's predictions on the test dataset can be found on Table 6. Its overall accuracy is 0.4571 which still is low for practical usage. The statistics by class can be found in Table 7.

		True level			
		Low	Medium	High	Total
Predicted level	Low	18	15	3	36
	Medium	34	52	29	115
	High	5	9	10	24
	Total	57	76	42	175

Table 6: One-vs-rest Classifier confusion matrix

Statistic	Low	Medium	High
Sensitivity	0.3158	0.6842	0.2381
Specificity	0.8475	0.3636	0.8947
Prevalence	0.3257	0.4343	0.2400
Detection Rate	0.1029	0.2971	0.0571
Detection Prevalence	0.2057	0.6571	0.1371
Balanced Accuracy	0.5816	0.5239	0.5664

Table 7: One-vs-rest Statistics by Class

5.1.4 Decision Tree

A conditional inference tree as specified in Hothorn, Hornik, and Zeileis's paper [7] has yielded the decision tree in Figure 5. A confusion matrix on the model's predictions on the test dataset can be found on Table 8. Its overall accuracy is 0.4663 which still is low for practical usage, but slightly better than the one-vs-rest classifier which is impressive considering the tree is minimalistic in its choice of nodes. The statistics by class can be found in Table 9.

		True level			
		Low	Medium	High	Total
Predicted level	Low	28	30	9	67
	Medium	28	46	25	99
	High	2	1	9	12
	Total	58	77	43	178

Table 8: Decision Tree confusion matrix

The importance of the count of high concreteness words have repeatedly shown up in many of our tested models which gives a strong indication that using NLP techniques on our response might yield rich information not usually attainable with other methods.

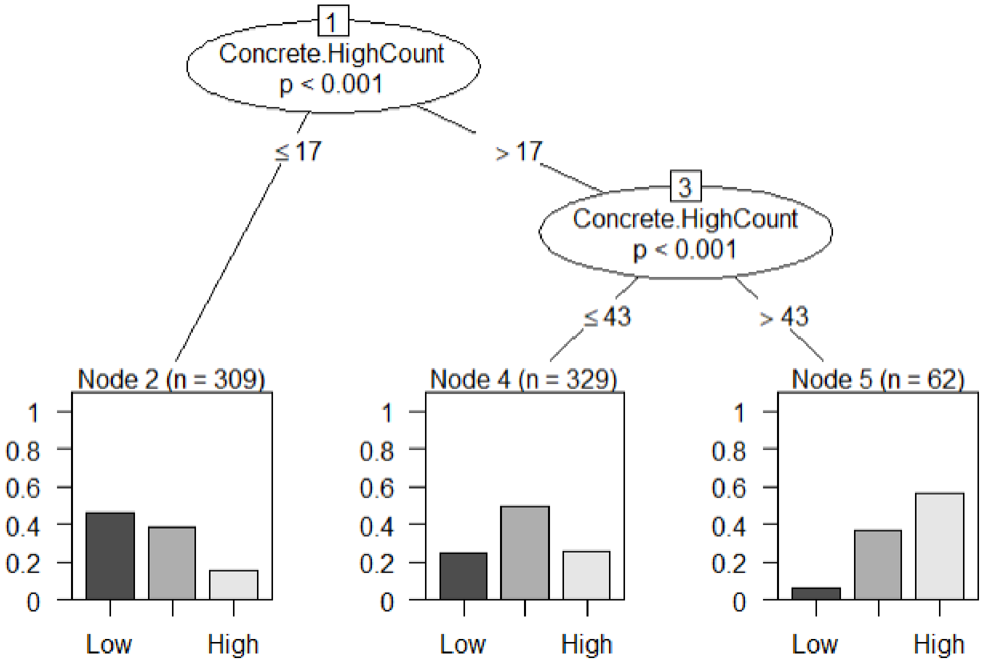


Figure 5: Concreteness Decision Tree

Statistic	Low	Medium	High
Sensitivity	0.4828	0.5974	0.2093
Specificity	0.6750	0.4752	0.9778
Prevalence	0.3258	0.4326	0.2416
Detection Rate	0.1573	0.2584	0.0506
Detection Prevalence	0.3764	0.5562	0.0674
Balanced Accuracy	0.5789	0.5363	0.5935

Table 9: Decision Tree Statistics by Class

5.2 Prediction with natural language processing techniques

5.2.1 BiLSTM Classifier

Flair[1] was used to implement BiLSTMs[8] for this study. The LSTM (Long Short Term Memory) architecture was explicitly designed to remember information over long periods of time, similar to recurring neural networks (RNN) who are also built to carry contextual information, but suffer from the vanishing or exploding gradients problem. Bidirectional LSTMs will run our inputs from start to end and end to start, preserving context both ways, which is useful for language problems. Due to these reasons, BiLSTMs have been at the forefront of NLP advancement in the recent years, alongside Transformers.

The word embeddings used are GloVe[15] and Flair's two embeddings[2] news-forward and news-backward.

		True level		
		Low	Not Low	Total
Predicted level	Low	0	2	2
	Not Low	35	72	107
Total		35	74	109

Table 10: BiLSTM binary classifier confusion matrix

Statistic	Score	Low	Not Low
Precision		0.0000	0.6729
Recall		0.0000	0.9730
F1 Score		0.0000	0.7956
F1 Score (micro)	0.6606		
F1 Score (macro)	0.3978		
Accuracy	0.6606		

Table 11: BiLSTM binary classifier statistics

For the binary model (Low vs Not Low), we can see in Table 10 that the BiLSTM model largely failed to predict Low responses, falling back to mode collapse, almost always predicting Not Low, in an attempt to achieve the highest accuracy it can.

		True level			
		Low	Medium	High	Total
Predicted level	Low	29	38	24	91
	Medium	7	7	3	17
	High	0	1	0	1
	Total	36	46	27	109

Table 12: BiLSTM multiclassifier confusion matrix

For the multiclass model (Low vs Medium vs High), we can see in Table 12 that the BiLSTM model largely failed to predict Low responses, falling back to mode

Statistic	Score	Low	Medium	High
Precision		0.3187	0.4118	0.0000
Recall		0.8056	0.1522	0.0000
F1 Score		0.4567	0.2222	0.0000
F1 Score (micro)	0.3303			
F1 Score (macro)	0.2263			
Accuracy	0.3303			

Table 13: BiLSTM multiclassifier statistics

collapse, almost always predicting Not Low, in an attempt to achieve the highest accuracy it can. The accuracy is at 0.3303 which is not much better than randomly guessing.

5.2.2 Transformer model

Flair[1] was used to implement Transformers for this study. The Transformer[19] architecture, similar to RNNs and LSTMs, are designed to handle sequential data. It connects an encoder and a decoder through an attention mechanism, and does not need to handle data sequentially, allowing it to be parallelizable making it popular for transfer learning.

The pre-trained model of choice for this paper is RoBERTa[12] given its powerful performance while still keeping reasonable performance requirements for the machine used. The roberta-base transformer document embedding was used as well.

		True level		
		Low	Not Low	Total
Predicted level	Low	0	0	0
	Not Low	35	74	109
Total		35	74	109

Table 14: RoBERTa binary classifier confusion matrix

Statistic	Score	Low	Not Low
Precision		0.0000	0.6789
Recall		0.0000	1.0000
F1 Score		0.0000	0.8087
F1 Score (micro)	0.6789		
F1 Score (macro)	0.4044		
Accuracy	0.6789		

Table 15: RoBERTa binary classifier statistics

For the binary model (Low vs Not Low), we can see in Table 14 that the Transformer mode completely predicted Not Low for all responses in the test data.

		True level			
		Low	Medium	High	Total
Predicted level	Low	21	24	8	53
	Medium	14	22	18	54
	High	1	0	1	2
	Total	36	46	27	109

Table 16: RoBERTa multiclassifier confusion matrix

Statistic	Score	Low	Medium	High
Precision		0.3962	0.4074	0.5000
Recall		0.5833	0.4783	0.0370
F1 Score		0.4719	0.4400	0.0690
F1 Score (micro)	0.4037			
F1 Score (macro)	0.327			
Accuracy	0.4037			

Table 17: RoBERTa multiclassifier statistics

For the multiclass model (Low vs Medium vs High), we can see in Table 16 that the RoBERTa model largely avoided predicting High on the responses. On the Low and Medium classes, the F1 score and accuracy of this model is significantly better (0.4037 vs 0.3303) than the performance of the BiLSTM model. It likely is due to the fact that the pretrained models carry in a wealth of information that helps our low count dataset more than what word embeddings can give.

5.3 Prediction with classical techniques

Earlier in the analysis, we can see that the addition of the word concreteness variables have helped the simple models like decision trees and linear regression improve their performance. However, there are techniques much better suited to our goal of prediction accuracy than those we've tried for inferential purposes. The non-NLP models that we will be fitting in this study an SVM classifier and a Random Forest classifier.

5.3.1 SVM Classifier

The binary SVM classifier model was able to get a 0.6702 accuracy while having a higher F1 Score on the Low class than the RoBERTa model. While it was nice to see a model not mode collapsing onto Not Low, it still didn't outperform the null model with an accuracy of 0.6789.

The multiclassifier SVM model was able to get a 0.4762 accuracy. It has a more balanced prediction spread than the non-NLP models, with High having a representation in the prediction model as compared to largely being ignored.

		True level		
		Low	Not Low	Total
Predicted level	Low	7	6	13
	Not Low	56	119	175
Total	63	125	188	

Table 18: SVM binary classifier confusion matrix

Statistic	Score	Low	Not Low
Precision		0.5385	0.6800
Recall		0.1111	0.9520
F1 Score		0.1842	0.7933
F1 Score (micro)	0.6702		
F1 Score (macro)	0.4888		
Accuracy	0.6702		

Table 19: SVM binary classifier statistics

5.3.2 Random Forest Classifier

The binary Random Forest classifier model was able to get a 0.7119 accuracy, the highest of our models. For practical purposes though, the recall on Low at 0.1897 means that it isn't that effective still for the purposes of identifying the people in our community at risk of decreased mental health, though the relatively high precision of 0.7333 makes it so that this model tends to be correct when it does guess that someone is Low concreteness.

The three variables that have the highest mean decrease in accuracy (how much the prediction accuracy suffers when the variable is removed from the random forest) scores in both binary and multiclass random forests are:

- Extreme concreteness word count (Concreteness scores ¿4 in a 5 point scale)
- High concreteness word count (Concreteness scores ¿3 in a 5 point scale)
- Word count

The random forest analysis has again shown the value of the word concreteness dataset by Charbonnier and Wartena[4].

5.4 Dissonance between Human Raters

To put into context the difficulty of the task for humans, we can look at the differences between the ratings of two raters on a single response where available. We have 194 responses of 1269 that have been rated by two humans.

The difference between ratings have been found to have a mean of 1.052 and a median of 1. In a five-point scale, it is not a small difference to be having. It is important to realise this to put the performance of our models in context.

		True level			
		Low	Medium	High	Total
Predicted level	Low	25	17	5	47
	Medium	38	58	33	129
	High	0	6	7	13
	Total	63	81	45	189

Table 20: SVM multiclassifier confusion matrix

Statistic	Score	Low	Medium	High
Precision		0.5319	0.4496	0.5385
Recall		0.3968	0.7160	0.1556
F1 Score		0.4545	0.5524	0.2414
F1 Score (micro)	0.4762			
F1 Score (macro)	0.4161			
Accuracy	0.4762			

Table 21: SVM multiclassifier statistics

		True level		
		Low	Not Low	Total
Predicted level	Low	11	4	15
	Not Low	47	115	162
Total	58	119	177	

Table 22: Random forest binary classifier confusion matrix

Statistic	Score	Low	Not Low
Precision		0.7333	0.7099
Recall		0.1897	0.9664
F1 Score		0.3014	0.8185
F1 Score (micro)	0.7119		
F1 Score (macro)	0.5600		
Accuracy	0.7119		

Table 23: Random forest binary classifier statistics

		True level			
		Low	Medium	High	Total
Predicted level	Low	27	21	7	55
	Medium	29	45	26	100
	High	2	11	10	23
	Total	58	77	43	178

Table 24: Random forest multiclassifier confusion matrix

Statistic	Score	Low	Medium	High
Precision		0.4909	0.4500	0.4348
Recall		0.4655	0.5844	0.2326
F1 Score		0.4779	0.5085	0.3031
F1 Score (micro)	0.4607			
F1 Score (macro)	0.4298			
Accuracy	0.4607			

Table 25: Random forest multiclassifier statistics

6 Conclusion

Of the four predictive models we've created, the Random Forest achieved the highest F1 Scores on micro and individual classes on both the binary and multiclass predictor models, except for the SVM having a better F1 Score on the Medium class (0.5524 vs 0.5085). See tables 26 and 27 for the full summary of scores.

These scores are not yet ready for our models to be made publicly used as a prediction tool to identify the people in our society that are in need of mental help, but we have shown that individual word concreteness has a correlation to a response's concreteness level as a whole. In every model that the word concreteness features were included, accuracy improves.

Model	F1 Score (micro)	F1 Score (Low)	F1 Score (Medium)	F1 Score (High)
BiLSTM	0.3303	0.4567	0.2222	0.0000
RoBERTa	0.4037	0.4719	0.4400	0.0690
SVM	0.4762	0.4545	0.5524	0.2414
Random Forest	0.4607	0.4779	0.5085	0.3031

Table 26: Summary of multiclass predictors

Model	F1 Score (micro)	F1 Score (Low)	F1 Score (Not Low)
BiLSTM	0.6606	0.0000	0.7956
RoBERTa	0.6789	0.0000	0.8087
SVM	0.6702	0.1842	0.7933
Random Forest	0.7119	0.3014	0.8185

Table 27: Summary of binary predictors

7 Future Work and Recommendations

A larger dataset with a more human raters per response would greatly help the analyses. A dataset size of 1000 is small especially for NLP problems. Pre-trained models help, but not enough to bridge the domain-specific knowledge gap.

Class imbalance is negatively affecting the models, especially the NLP models that have ended up in mode collapse. Techniques can be applied to alleviate this such as making learning rates dynamically scale to the relative class sizes.

Hyperparameter tuning would also be a simple way to get a few more improvements in the F1 scores of our models, but the problem largely lies with the dataset and the nature of the problem being difficult even for humans with a mean difference of human raters' ratings being 1.052 in a 5 point scale.

NLP attempts to predict concreteness have generally failed, and the usage of specific domain knowledge through the word concreteness dataset have been valuable, so research in the direction of finding other possible non-machine learning ways to evaluate concreteness would work well to augment the word concreteness dataset in understanding and prediction response concreteness.

8 Appendix

8.1 Codebase

The full codebase is publicly available on GitHub at markangelogabriel/predictingconcreteness.

8.2 Original proposal

EFFECT OF MENTAL IMAGERY PARAMETERS ON THE RISK OF EXPERIENCING LONELINESS IN A PERIOD OF ISOLATION

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Background

The COVID-19 pandemic has forced a sudden change in society that we weren't fully prepared for. Self-isolation and physical distancing has been imposed on everyone in varying degrees and the effect of it on people's mental wellbeing is an area of interest, especially if a second or third wave of the pandemic will require people to undergo isolation again. Certain members of the community are going to be affected more than others from this rapid disruption of the day-to-day because they are not getting the usual levels of social interaction they need or are used to to maintain a healthy mental wellbeing. It is in our interest to find which members of our community are at most risk with a method that is highly accessible given the physical restrictions that such a societal condition imposes.

Close-ended numerical ratings are often lacking, yet are still commonly used as a shortcut for quantification of a person's mental state as there aren't many accessible alternatives. The surgent rise of the usage of AI and machine learning techniques to aid research in various fields has been a great boon to scientific progress, and the same is possible for psychology. A person's state of mind is possibly better evaluated by the open-ended nature of speech and actions, and Natural Language Processing can help us understand them better. One study [10] has attempted to develop

”semantic measures” using Natural Language Processing to statistically measure, differentiate, and describe psychological states.

Dr. Julie Ji’s research on mental imagery, the experience of perception in the absence of external sensory input, shows that the person’s quality of mental imagery-based simulations has a significant link to maintaining and amplifying emotional states [9]. In one study on mental imagery as a motivational amplifier to promote activities as a key treatment in depression [16], the Motivational Imagery group reported higher levels of motivation, anticipated pleasure, and anticipated reward for the planned activities compared to the Activity Reminder control group and the No-Reminder control group.

The CARE study is a survey study investigating which factors contribute to people’s mental wellbeing during, and after, periods of self-isolation, compared to that of just social-distancing. The survey has yielded over 1000 responses which will be the core dataset to be investigated in this project.

Aim

This project aims to understand the factors that contribute to people’s mental wellbeing during, and after periods of social isolation by delving into the rich data that is the participants’ open-text response to the scenario provided in the survey.

In this project, I propose to do three things:

- Find which mental imagery parameters are significant for predicting a person’s risk of loneliness in a prolonged isolation setting
- Design a method to extract significant mental imagery parameters from a person’s free-text response to an isolation scenario that starts negatively and ends positively
- Predict a person’s risk of loneliness in an isolation setting based on their mental imagery parameters

In addition, I aim to do exploratory data analysis to investigate natural clusters and relationships appearing from the data. If particular clusters show to be more susceptible to loneliness in isolation, it can be a quick and valuable tool to assess and approach patients before having access to a corpus to analyse.

The four core mental imagery parameters that we’re interested in are as follows:

- Number of discrete relevant problem-solving steps that helps the person to reach the desired goal or to overcome an obstacle along the way
- Solution effectiveness, or how much the person thinks the described solution would maximise positive and minimise negative consequences in both the short and long term, both personally and socially

- Solution concreteness, the degree to which the described solution reflects concrete plans, i.e. involving specific actions, times, places and people
- Emotional tone, the degree to which the participant sounds negative (downbeat/pessimistic/unsure) or positive (upbeat/optimistic/confident)

The dataset will be hand-graded on each of the four mental imagery parameters by research assistants to serve as the response variable that the NLP models will be trained on.

Method

Data cleaning will need to be done as there are participants who have skipped the mental imagery scenario question. Corpus cleaning will also be necessary to clean up typos, remove stop words (a, the, and, etc) and special characters, and eventually normalisation. Stemming (the process of eliminating affixes from a word to find the root word) will also be applied to the corpus.

Each of the four mental imagery parameters will require their own individual regression analysis with the help of NLP techniques to arrive at a satisfactory model. Due to the time needed, it would be beneficial to first find which of the parameters are significant to save time being spent on potentially unimportant variables.

As for the specific variables that would make the model for each of the four mental imagery parameters, further research and experimentation will need to be done. Some early ideas that might make it to the end models are:

- Number of discrete relevant problem-solving steps: POS tagging, verb count
- Solution effectiveness: sentiment analysis
- Solution concreteness: named entity count
- Emotional tone: sentiment analysis

Finally, once the individual mental imagery parameter models are performing satisfactorily, we'll evaluate the effectiveness of all of them combined to predict a person's risk of loneliness at certain phases of isolation.

Software and Hardware Requirements

Python 3.8 will be used for this project. BERT [6] will be used as the NLP framework of choice given its impressive performance even on small datasets. There are no special hardware requirements.

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