Assessment of Stress-Buffering Effects of Uplift Events on Overwhelmed Teenagers from Microblogs

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Abstract

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1. Introduction

Stress. Life is always full of ups and downs. The serious mental health problems caused by stress has become hot issues that are widely concerned around the world. According to the newest report of American Psychological Association, the youngest adults are most likely of all generations to report poor mental health in America, and 91 percent of Gen-Zs between ages 18 and 21 say they have experienced physical or emotional symptom due to stress in the past month compared to 74 percent of adults overall (APA, 2018). Accumulated stress comes from daily hassles, major stressful events and environmental stressors could drain people's inner resources, leading to psychological maladjustment, ranging from depression to suicidal behaviours (Nock et al., 2008). Nowadays more than 30 million Chinese teenagers are suffering from psychological stress, and nearly 30% have a risk of depression (Youth and Center, 2019).

Stress-buffering. Restoring is an essential process in human's stress coping system (Susan, 1984) to help get out of overwhelmed status. Traditional psychology research shows that stress-restoring could function through various ways, including exercise[xx], self-esteem [xx], changing environments [xx], chatting with friends [xx], writing diaries [xx] and so on. The specific restoring restoring mode remains to be further explored.

With the epidemic of social media among adolescents, it provides a new channel for timely and non-invasive exploration of users' mental health status. Previous studies have shown that it is feasible and reliable to detect user's psychological stress and stressor events, and predict future psychological stress trends through social network data. However, research on stress-buffering effects of uplift events from social networks still calls for more exploration. This article will explore the restoring impact of uplift events from microblogs, help scheduling positive interventions, and predict future stress.

2. Literature review

2.1. Restorative function of positive life events.

Positive life events are conceptualized as exerting a protective effect on emotional distress in psychological literature (Cohen et al., 1984; Needles and Abramson, 1990). Many psychological researchers have focused on the restorative function of positive events with respect to physiological, psychological, and social coping resources. (Folkman and Moskowitz, 2010) identified three classes of coping mechanisms that are associated with positive emotion during chronic stress: positive reappraisal, problem-focused coping, and the creation of positive events. The author also considered the possible roles of positive emotions in the stress process, and incorporated positive emotion into a revision of stress and coping theory in the work (Folkman, 1997). They conducted a longitudinal study of the care giving partners of men with AIDS and described coping processes that were associated with positive psychological states in the context of intense distress.

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The protective effect of uplift events was hypothesized to operate in both directly (i.e., more positive uplift events people experienced, the less distress they experience) and indirectly ways by 'buffering' (Cohen and Hoberman, 2010). In the direct way, the more positive uplift events people experienced, the less distress they experience. While in the indirectly way, positive life events play its role by buffering the effects of negative events on distress. A pioneer experiment conducted by Reich and Zautra provided enlightening evidence for us (Shahar and Priel, 2002). In this experiment, sampled college students who reported initial negative events were encouraged to engage in either two or twelve pleasant activities during one-month, and compared with students in the controlled group experiencing no pleasant activities. Results indicated that participants in the two experimental groups reported greater quality of life compared with controlled students, and participants who engaged in twelve uplift events exhibited lower stress compared with whom engaging two or none uplifts, implicating the protective effect of uplift events on adolescents.

H1: Positive events could buffer teen's psychological stress.

Positive events are verified as protective factors against loneliness, suicide, daily stressors, depression and helping improve health. (Chang et al., 2015) investigated the protective effect of positive events in a sample of 327 adults, and found that the positive association between loneliness and psychological maladjustment was found to be weaker for those who experienced a high number of positive life events, as opposed to those who experienced a low number of positive life events. This is assistant with the conclusion made by (Kleiman et al., 2014) that positive events act as protective factors against suicide individually and synergistically when they co-occur, by buffering the link between important individual differences risk variables and maladjustment. Through exploring naturally occurring daily stressors, (Ong et al., 2006) found that over time, the experience of positive emotions functions to assist high-resilient individuals to recover effectively from daily stress. In the survey made by (Santos et al., 2013), strategies of positive psychology are checked as potentially tools for the prophylaxis and treatment of depression, helping to reduce symptoms and for prevention of relapses. Through a three-week longitudinal study, (Bono et al., 2013) examined the correlation between employee stress and health and positive life events, and concluded that naturally occurring positive events are correlated with decreased stress and improved health.

Due to the immature inner status and lack of experience (Vitelli, 2014), young people exhibit more exposure to uplift events compared with adults, such as satisfying social interactions, excellent academic performance and pleasant entertainments. Researchers indicate that positive events mitigate the relation between negative events and maladjustment in samples of adolescents experiencing family transitions (Doyle et al., 2003). The written expression of positive feelings has also be shown to prompt increased cognitive re-organization among an undergraduate student group (Coolidge, 2009). Positive uplifts can not only help reinforce adolescents' sense of well-being, help restore the capacity for dealing with stress, but also have been linked to medical benefits, such as improving mood, serum cortisol levels, and lower levels of inflammation and hyper coagulability (Jain et al., 2010). Through examining the relationship between self-reported positive life events and blood pressure in 69 sixth graders, researchers found that increased perceptions of positive life events might act as a buffer to elevated blood pressure in adolescents (Caputo et al., 1998).

H2: High frequency of positive events better relieve stress.

2.2. Assessment of Stress-buffering Effects of Positive Events

Measuring the Impact of Uplift Events with traditional psychology scales. To measure the impact of uplift events, Doyle *et al.* Kanner et al. (1981) conducted *Hassles and Uplifts Scales*, and concluded that the assessment of daily hassles and uplifts might be a better approach to the prediction of adaptational outcomes than the usual life events approach. Silva *et al.* Silva et al. (2008) presented the *Hassles & Uplifts Scale* to assess the reaction to minor every-day events in order to detect subtle mood swings and predict psychological symptoms. To measure negative interpretations of positive social events, Alden *et al.* Alden et al. (2008) proposed the interpretation of positive events scale (*IPES*), and analyzed the relationship between social interaction anxiety and the tendency to interpret positive social events in a threat-maintaining manner. Mcmillen *et al.* Mcmillen and Fisher (1998) proposed the *Perceived Benefit Scales* as the new measures of self-reported positive life changes after traumatic stressors, including lifestyle changes, material gain, increases in selfefficacy, family closeness, community closeness, faith in people, compassion, and spirituality. Specific for college students, Jun-Sheng *et al.* Jun-Sheng (2008) investigated in 282 college students using the *Adolescent Self-Rating Life Events Checklist*, and found that the training of positive coping style is of great benefit to improve the mental health of students. Previous exploration for the protective effect of uplift events on adolescents are mostly conducted in psychological area, relying on traditional manpower-driven investigation and questionnaire. The pioneer psychological researches provide us valuable implications and hypothesis, while limited by labor cost, and single questionnaire based method.

Sensing adolescent stress from social networks. With the high development of social networks, researches explored applying psychological theories into social network based stress mining, offering effective tools for adolescent stress sensing. As billions of adolescents record their life, share multi-media content, and communicate with friends through such platforms, e.g., Tencent Microblog, Twitter, Facebook and so on, researchers tend to digging psychological status from the self-expressed public data source. Xue *et al.* Xue et al. (2014) proposed to detect adolescent stress from single microblog utilizing machine learning methods by extracting stressful topic words, abnormal posting time, and interactions with friends. Lin *et al.* Lin et al. (2014) construct a deep neural network to combine the high-dimensional picture semantic information into stress detecting. Based on the stress detecting result, Li *et al.* Li et al. (2015)adopted a series of multi-variant time series prediction techniques (i.e., Candlestick Charts, fuzzy Candlestick line and SVARIMA model) to predict the future stress trend and wave. Taking the linguistic information into consideration, Li *et al.* Li et al. (2017a) employed a NARX neural network to predict a teen's future stress level referred to the impact of co-experiencing stressor events of similar companions. To find the source of teens' stress, previous work Li et al. (2017b) developed a framework to extract stressor events from microblogging content and filter out stressful intervals based on teens' stressful posting rate. All above pioneer work focused on the generation and development of teens' stress, providing solid basic techniques for broader stress-motivated research from social networks. Based on such research background, this paper starts from a completely new perspective, and focuses on the buffering effect of positive events on restoring stress. Thus we push forward the study from how to find stress to the next more meaningful stage: how to deal with stress.

H3: Positive events could predict teen's future stress.

3. Current study

In this paper, we aim to continually mine the restoring impact of uplift events leveraging abundant data source from microblogs, to further provide guidance for school and parents that when and which kind of uplift events could help relieve students' overwhelmed stress in both stress prevention and stress early stopping situations. To model such a practical application problem, several challenges exist. 1) How to extract uplift events from microblogs and identify corresponding impact interval? The impact of uplift events is highlighted when the teen is under stress, with various relative temporal order. Extracting such scenarios from teen's messy microblogs is the first and basic challenge for further analysis. 2) How to qualitatively and quantitatively measure the restoring impact conducted by uplift events? There are multiple clues related to teens' behaviours from microblogs, i.e., depressive linguistic content, abnormal posting behaviours. The teen might act differently under similar stressful situations when the uplift event happens or not. It is challenging to find such hidden correlation between uplift events and teen's behavioural characters.

Moreover, for different types of uplift events, the restoring impact might be different. And for each individual, the protective and buffering effect for stress might also varies according to the personality. All these questions guide us to solve the problem step by step.

In this paper, we first conduct a case study on real data set to observe the posting behaviours and contents of stressful teens under the influence of uplift events. We conduct the case study on the real data set of 124 high school students associated with the school's scheduled uplift and stressor event list. Several observations are conducted to guide the next step research. Next, we extract uplift events and the corresponding impacted interval from microblogs. We define and extract structural uplift events from posts using linguistic parser model based on six-dimensional uplift scale and LIWC lexicons. Independent stressful intervals (SI) and stressful intervals impacted by uplifts (U-SI) are extracted considering temporal orders. To quantify the restoring impact of uplift events, we describe a teen's stressful behaviours in three groups of measures (stress intensity, posting behaviour, linguistic), and model the impact of uplift events as the statistical difference between the sets of SI and U-SI in two aspects: the two-sample based method is employed for variation detection, and the t-test correlation is conducted to judge the monotonous correlation.

4. Study1: Observation on the stress-relieving ability of school scheduled uplift events

4.1. Sample

We built our dataset based on two sources: 1) the microblogs of students coming from Taicang High School, collected from January 1st, 2012 to February 1st, 2015; and 2) list of scheduled school events, with exact start and end time. We filtered out 124 active students according to their posting frequency from over 500 students, and collected their microblogs throughout the whole high school career. Totally 29,232 microblogs are collected in this research, where 236 microblogs per student on average, 1,387 microblogs maximally and 104 posts minimally.

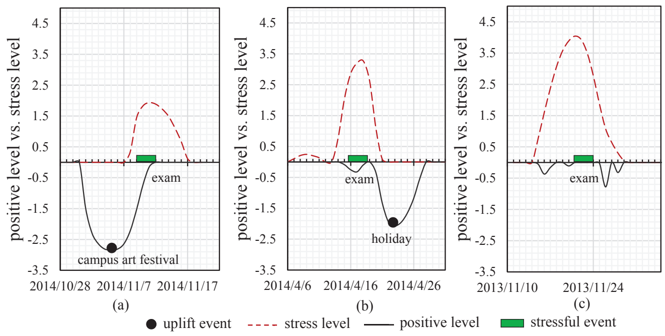
Uplift events and stressor events. The list of weekly scheduled school events (from February 1st, 2012 to August 1st 2017) are collected from the school's official website [1], with detailed event description and grade involved in the event. There are 122 stressor events and 75 uplift events in total. Here we give the examples of scheduled uplift and stressor events in high school life, as shown in Table 1. Comparing the stress curves *a), b)* with *c)*, when an uplift event (*campus art festival, holiday* here) happens, the overall stress intensity during the stressful period is reduced. An uplift event might happen before a teen's stress caused by scheduled stressor events (*example a*), conducting lasting easing impact; Meanwhile, an uplift event might also happen during (*example b*) or at the end of the stressful period, which might promote the teen out of current stressful status more quickly. There are 2-3 stressor events and 1-2 uplift event scheduled per month in current study.

Table 1: Examples of school scheduled uplifts and stressor events.

Type	Date	Content	Grade
stressor event	2014/4/16	*first day of mid-term exam*	grade1,2
uplift event	2014/11/5	*campus art festival*	grade1,2,3

Stress detected from microblogs. Since our target is to observe the restoring impact of uplift events for teenagers under stress. Based on previous research Xue et al. (2013), we detected the stress level (ranging from 0 to 5) for each post; and for each student, we aggregated the stress during each day by calculating the average stress of all posts. The positive level (0-5) of each post is identified based on the frequency of positive words (see Section 5 for details). Figure 1 shows three examples of a student's stress fluctuation during three mid-term exams, where the uplift event *campus art festival* was scheduled ahead of the first exam, the uplift event *holiday* happened after the second exam, and no scheduled uplift event was found nearby the third exam. The current student exhibited differently in above three situations, with the stress lasting for different length and with different intensity.

Figure 1: Examples of school related stressor events, uplift events and a student's stress fluctuation



4.2. Findings

To further observe the influence of uplift events for students facing stressor events, we statistic all the stressful intervals Li et al. (2017b) detected surround the scheduled examinations over the 124 students during their high school career. For each student, we divide all the stressful intervals into two sets: 1) In the original sets, stress is caused by a stressor event, lasting for a period, and no other intervention (namely, uplift event) occurs. We call the set of such stressful intervals as **SI**; 2) In the other comparative sets, the teen's stressful interval is impacted by an uplift event *x*, we call the set of such stressful intervals as **U-SI**. Thus the difference under the two situations could be seen as the restoring impact conducted by the uplift event of type *x*.

Figure 2 shows five measures of each teen during the above two conditions: the *accumulated stress*, the *average stress* (per day), the *length of stressful intervals*, the *frequency of academic topic words*, and the *ratio of academic stress among all types of stress*. For each measure, we calculate the average value over

[1] http://stg.tcedu.com.cn/col/col82722/index.html

all eligible slides for each student. Comparing each measure in scheduled exam slides under the two situations: 1) existing neighbouring uplift events or 2) no neighbouring scheduled uplift events, we find that students during exams with neighbouring uplift events exhibit less average stress intensity (both on accumulated stress and average stress), and the length of stress slides are relatively shorter.

Further, we statistic the frequency of academic related topic words for each exam slide (as listed in Table 2), and look into the ratio of academic stress among all five types of stress. Results in Figure 2 shows that most students talked less about the upcoming or just-finished exams when uplift events happened nearby, with lower frequency and lower ratio.

Table 2: Examples of academic topic words from microblogs.

exam, fail, review, score, test paper, rank, pass, math, chemistry
homework, regress, fall behind, tension, stressed out, physics,
nervous, mistake, question, puzzle, difficult, lesson, careless

The statistic result shows clues about the stress-relieving ability of scheduled uplift events, which are constant with the psychological theory (Cohen et al., 1984; Cohen and Hoberman, 2010; Needles and Abramson, 1990). Thus we conduct our research under the assumption that uplift events can bring positive influence to stressed teens in various situations with multi-types. The ultimate problem we target to solve is how to quantify the influence of positive events, and then predict the stress-buffering result based on teen's microblogs, thus to provide further guidance for planning campus activities to help relive students' stress effectively. Given an uplift event with specific type, we consider its impact by comparing the teen's behavioral measures under the two situations (SI and U-SI) defined in section 4, and structure the impact from three aspects:

1. Impact interval of uplifts. To study the impact of uplift events from microblogs, two fundamental factors are identifying the exact time when the uplift event happens, and the corresponding stressful interval it impacts. The temporal order between uplift events and the teen's stress series varies in different situations, and its a challenge to match the uplift event to the right stressful interval it actually impacts.

2. Restoring patterns of uplifts. As the restoring impact of uplift events relieves the teen's stress and exhibits in multiple aspects (e.g., the changes in posting behavior, linguistic expression, and stress intensity from microblogs), it's meaningful to extract the stress-related restoring patterns and describe the restoring impact of uplift events structurally.

*3. Quantified impact of uplifts.*Different types of uplift events might conduct restoring impact with different intensity. This paper will measure the impact of an uplift event in terms of its interval and restoring patterns.

In following studies, we will quantify such impact from multiple views, and apply it into future stress prediction.

5. Study2: Identify Positive Events and the Corresponding Impact Interval from microblogs

In this section, we first introduce the procedure to extract uplift events and stressful intervals from teens' microblogs. The uplift events are extracted from microblogs applying LTP natural language processing segmentation and parser models Zhang et al. (2008). Stressful intervals are identified using probability based statistical method according to the teen's stressful posting frequency. We judge whether each stressful interval is correlated with neighboring uplift events, thus to classify all stressful intervals into two sets: SI and U-SI.

5.1. Uplift Events

Linguistic structure. Let $u = [type, \{role, act, descriptions\}]$ be an uplift event, where the element *role* is the subject who performs the *act*, and *descriptions* are the key words related to u. According to psychological scales Kanner et al. (1981); Jun-Sheng (2008), teens' uplift stressors mainly focus on six aspects, as $\mathbb{U}$ = { *'entertainment', 'school life', 'family life', 'pear relation', 'self-cognition', 'romantic'*}, $\forall u$, $u._{type} \in \mathbb{U}$. Similar to uplift event, let $e = [type, \{role, act, descriptions\}]$ be a stressor event. According to psychological questionnaires Jiang (2000); Baoyong and Ying (2002); Kanner et al. (1981); Yan et al. (2010), we classify stressor events into five types, as $\mathbb{S}$ = { *'school life', 'family life', 'pear relation', 'self-cognition', 'romantic'*}, $\forall e$, $e._{type} \in \mathbb{S}$.

Lexicon. We construct our lexicon for six-dimensional uplift events from two sources. The basic positive affect words are selected from the psychological lexicon SC-LIWC (e.g., *expectation*, *joy*, *love* and *surprise*)Tausczik and Pennebaker (????). Then we build six uplift event related lexicons by expanding the basic positive words from the data set of teens' microblogs, and divide all candidate words into six dimensions corresponding

Table 3: Examples of topic words for uplift events.

Dimension	Example words	Total
entertainment	hike, travel, celebrate, dance, swimming, ticket, shopping, air ticket, theatre, party, Karaoke, self-driving tour, game, idol, concert, movie, show, opera, baseball, running, fitness, exercise	452
school life	reward, come on, progress, scholarship,admission, winner, diligent, first place, superior hardworking, full mark, praise, goal, courage, progress, advance, honor, collective honor	273
romantic	beloved, favor, guard, anniversary, concern, tender, deep feeling, care, true love, promise, cherish, kiss, embrace, dating, reluctant, honey, sweetheart, swear, love, everlasting, goddess	138
pear relation	listener, company, pour out, make friends with, friendship, intimate, partner, team-mate, brotherhood	91
self-cognition	realize, achieve, applause, fight, exceed, faith, confidence, belief, positive, active, purposeful	299
family life	harmony, filial, reunite, expecting, responsible, longevity, affable, amiability, family, duty	184

to six types of uplift events, containing 452 phrases in *entertainment*, 184 phrases in *family life*, 91 phrases in *friends*, 138 phrases in *romantic*, 299 phrases in *self-recognition* and 273 phrases in *school life*, with totally 2,606 words, as shown in Table 3. Additionally, we label *role* words (i.e., *teacher*, *mother*, *I, we*) in the uplift lexicon.

The examples of teens' microblogs describing uplift events are listed in Table 4. For the post '*Expecting Tomorrow' Adult Ceremony[Smile][Smile]* ', we translate it into *act* = *'expecting'*, *object* = *'Adult Ceremony'*, and *type* = *'self-cognition'*.

Table 4: Structured extraction of positive events from microblogs.

I am really looking forward to the spring outing on Sunday now. (Doer:*I*, Act:*looking forward*, Object:*spring outing*)
My holiday is finally coming [smile]. (Doer:*My holiday*, Act:*coming*, Object:*[smile]*)
First place in my lovely math exam!!! In memory of it. Object:*first place, math, exam, memory*)
You are always here for me like sunshine. (Doer:*You*, Object:*sunshine*)
Thanks all my dear friends taking the party for me. Happiest birthday!!! (Doer:*friends*, Act:*thanks*, Object:*party, birthday*)
I know my mom is the one who support me forever, no matter when and where. (Doer:*mom*, Act:*support*)
Expecting Tomorrow' Adult Ceremony[Smile][Smile] (act: *expecting*, object:*Adult Ceremony*)

Parser relationship. For each post, after word segmentation, we parser current sentence to find its linguistic structure, and then match the main linguistic components with uplift event related lexicons in each dimension. The parser model in Chinese natural language processing platform Che et al. (2010); Zhang et al. (2008) is adopted in this part, which identifies the central verb of current sentence first, namely the *act*, and constructs the relationship between the central verb and corresponding *role* and *objects* components. By searching these main elements in uplift event related lexicons, we identify the existence and type of any uplift event. Due to the sparsity of posts, the *act* might be empty. The *descriptions* are collected by searching all nouns, adjectives and adverbs in current post. In such way, we extract structured uplift events from teens' microblogs.

5.2. *Impact Interval of Current Positive Event*

Basically, in this part, we identify stressful intervals from time line thus to support further quantifying the influence of an uplift event. Splitting interval is a common time series problem, and various solutions could be referred. Here we identify the teen's stressful intervals in three steps.

In the first step, we extract uplift events, stressor events and filter out candidate intervals after a smoothing process. Since a teen's stress series detected from microblogs are discrete points, the loess method Cleveland and Devlin (1988) is adopted to highlight characteristics of the stress curve. The settings of parameter *span* will be discussed in the experiment section, which represents the percentage of the selected data points in the whole data set and determines the degree of smoothing. The details are present as Algorithm 7.2 of the appendix.

In the second step, applying the Poisson based statistical method proposed in Li et al. (2017b), we judge whether each candidate interval is a confidential stressful interval. The details are present as Algorithm 7.3 of the appendix.

Finally, we divide the stressful intervals into two sets: the SI set and the U-SI set, according to its temporal order with neighboring uplift events. The details are present as Algorithm 7.4 of the appendix.

6. Study3: Quantify the impact of uplift events

To quantify the restoring impact of uplift event, in this section, we propose to model the impact as the teen's behavioral differences in two cases: 1) stressful intervals unaffected by uplift events (SI), and 2) stressful intervals impacted by uplift events (U-SI). Multiple stress and positive emotion related measures are proposed to describe the correlation between SI and U-SI, and we quantify such differences as correlations using a two-sample based statistical method.

6.1. Restoring Patterns and Behavioral Measures

To extract the restoring patterns $\boldsymbol{A}$ for each type of uplift events, we describe a teen's positive and stressful behavioral measures in SI and U-SI sets from three aspects: posting behavior, stress intensity, and linguistic expressions.

Posting behavior. Stress could lead to a teen's abnormal posting behaviors, reflecting the teen's changes in social engagement activity. For each stressful interval, we consider three measures of posting behaviors in each time unit (day), and present each measure as a corresponding series. The first measure is *posting frequency*, representing the total number of posts per day. Research in Li et al. (2017b) indicates that overwhelmed teens usually tend to post more to express their stress for releasing and seeking comfort from friends. Further, the second measure *stressful posting frequency* per day is based on previous stress detection result and highlights the stressful posts among all posts. Similarly, the third measure is the *positive posting frequency*, indicating the number of positive posts per day. The forth measure *original frequency* is the number of original posts, which filters out re-tweet and shared posts. Compared to forwarded posts, original posts indicate higher probability that teens are talking about themselves. Thus for each day in current interval, the teen's posting behavior is represented as a four-dimension vector.

Stress intensity. We describe the global stress intensity during a stressful interval through four measures: *sequential stress level, length, RMS,* and *peak*. Basically, *stress level* per day constructs a sequential measure during a stressful interval, recording stress values and fluctuation on each time point. The *length* measures the lasting time of current stressful interval. As uplift events might conduct impact on overwhelmed teens, and postpone the beginning or promote the end of the stressful interval, we take the *length* as a factor representing the interval stress intensity. To quantify the intensity of fluctuations for stress values, we adopt the *RMS* (root mean square) of stress values through the interval as the third measure. In addition, the *peak* stress value is also a measure to show the maximal stress value in current interval.

Linguistic expressions. We extract the teen's positive and stressful expressions from the content of posts in SI and U-SI sets, respectively. The first linguistic measure is the frequency of *positive word*, which represents the positive emotion in current interval. The second measure is the frequency of *uplift event topic words* in six dimensions, reflecting the existence of uplift events. Another important factor is wether existing *self-mentioned words* (i.e., *'I','we','my'*). Self-mentioned words show high probability that the current stressor event and stressful emotion is related to the author, rather than the opinion about a public event or life events about others.

Except uplift-related linguistic descriptions, we also take stressful linguistic characters as measures, which is opposite with positive measures, while also offers information from the complementary perspective. The first stressful linguistic measure is the frequency of *stressor event topic words* in five dimensions, which represents how many times the teen mentioned a stressor event, indicating the degree of attention for each type of stressor event. The frequency of *pressure words* is the second stressful linguistic measure, reflecting the degree of general stress emotion during the interval. We adopt this measure specifically because in some cases teens post very short tweets with only stressful emotional words, where topic-related words are omitted.

Next, based on the posting behavior, stress intensity and linguistic measures from both the stressful and positive views, we quantify the difference between SI and U-SI sets, thus to measure the impact of uplift events.

6.2. Quantify the Correlation

In our problem, there are two sets of stressful intervals to compare: the SI set and the U-SI set, containing stressful intervals unaffected by uplift events and stressful intervals impacted by uplift events, respectively. The basic elements in each set are stressful intervals, i.e., the sequential stress values in time line, which are modeled as multi-dimensional points according to the three groups of measures in section **??**. Thus we formulate this comparison problem as finding the correlation between the two sets of multi-dimension points. Specifically, we adopt the multivariate two-sample hypothesis testing method Li et al. (2017); Johnson and Wichern (2012) to model such correlation. In this two-sample hypothesis test problem, the basic idea is judging whether the multi-dimension points (i.e., stressful intervals) in set SI and set U-SI are under different statistical distribution. Assuming the data points in SI and U-SI are randomly sampled from distribution $F^{(1)}$ and $F^{(2)}$, respectively, then the hypothesis is denoted as:

$$H_0 : F^{(1)} = F^{(2)} \quad versus \quad H_1 : F^{(1)} \neq F^{(2)}. \tag{1}$$

Under such hypothesis, H_0 indicates points in SI and U-SI are under similar distribution, while H_1 means points in SI and U-SI are under statistically different distributions, namely uplift events have conducted obvious restoring impact on current stressed teen. Next, we handle this two-sample hypothesis test problem based on both positive and stressful behavioral measures (i.e., *posting behavior*, *stress intensity* and *linguisitc expressions*), thus to quantify the restoring patterns of uplift events from multi perspectives.

As a classic statistical topic, various algorithms have been proposed to solve the two-sample hypothesis testing problem. Since each point in the two sets (SI and U-SI) is depicted in multi-dimensions, here we take the KNN (k nearest neighbors) Schilling (1986) based method to judge the existence of significant difference between SI and U-SI. For simplify, we use the symbol A_1 to represent set SI, and A_2 represent set U-SI, namely A_1 and A_2 are two sets composed of stressful intervals. In the KNN algorithm, for each point ℓ_x in the two sets A_1 and A_2, we expect its nearest neighbors (*the most similar points*) belonging to the same set of ℓ_x, which indicates the difference between the points in the two cases.

The model derivation process is described in detail in the 7.5 part of the appendix.

6.3. Temporal Order

To measure the intensity of stress changes in the two sets (SI and U-SI) of intervals, for each stressful interval, we further quantify its stress intensity by comparing with the front and rear adjacent intervals, respectively. For a stressful interval $I =< t_i, t_{i+1}, \cdots, t_j >$, let $I^{front} =< t_m, \cdots, t_{i-1} >$ be the adjacent interval before I, and $I^{rear} =< t_{j+1}, \cdots, t_n >$ be the rear adjacent interval of I. The length of I^{front} and I^{rear} are set to $|I|$. For the set of stressful intervals SI composed of $< I_1, I_2, \cdots, I_N >$, the corresponding sets of adjacent front and rear intervals are denoted as SI^{front} and SI^{rear}. Similarly, for the set of stressful intervals $U-SI = < UI_1, UI_2, \cdots, UI_M >$ impacted by uplift events, the corresponding sets of adjacent front and rear intervals are denoted as USI^{front} and USI^{rear}. We compare the intensity of stress changes in following four situations, where $g(.)$ is the function comparing two sets.

① $g(SI, SI^{front})$ returns if intensive change happens when stressful intervals begin.

② $g(SI, SI^{rear})$ returns if the teen's stress change intensively after the stressful intervals end.

③ $g(USI, USI^{front})$ returns if intensive change happens when stressful intervals affected by uplift events appears.

④ $g(USI, USI^{rear})$ returns if stress change intensively after stressful intervals affected by uplift events end.

In our problem, taking the comparison between SI and SI^{rear} for example, the basic computation element $I_k \in SI \cup SI^{rear}$ in both sets is a multi-dimension interval. Here we adopt the t-test method as the intensity computation function $g(.)$. The t-test algorithm measures if intensive positive or negative monotonous correlation exists between two sample sets. The function $g(.) = t_{score} \in$ (-1,1) is represented as:

$$g(SI, SI^{rear}) = \frac{\mu_{SI} - \mu_{SI^{rear}}}{\sqrt{\frac{(n_1-1)\sigma_{SI}^2+(n_2-1)\sigma_{SI^{rear}}^2}{n_1+n_2-2}(\frac{1}{n_1} - \frac{1}{n_2})}} \tag{2}$$

where μ_{SI} and $\mu_{SI^{rear}}$ are the mean stress values of intervals in sets SI and SI^{rear}, and σ_{SI} and $\sigma_{SI^{rear}}$ are the variance stress values of intervals in sets SI and SI^{rear}, respectively. If $g(SI, SI^{rear}) > \alpha$, stress intensity in SI^{rear} show significant decrease compared with SI (monotonic negative effect). If $g(SI^{front}, SI) < -\alpha$, stress intensity in SI show significant increase compared with SI^{front} (monotonic positive effect). Here we adopt $\alpha = 1.96$, $P = 0.025$. We conduct comparison for above four situations, to observe whether the occurrence of uplift events relieve the monotonic negative effect of $g(SI, SI^{rear})$ and the monotonic positive effect of $g(SI^{front}, SI)$.

Algorithm 1: Identify the restoring impact of uplift events.

Input: SI: Set of stressful intervals caused by S';
U-SI: Set of stressful intervals affected by U';
Output: Restoring impact of uplift U' on stressor S': $\boldsymbol{A}$

```
Initialize: H_1, H^front, H^rear = false;
if f(SI, USI) > α then
    H_1 = ture;
if g(SI, SI^rear) > α && g(SI, SI^rear) > g(USI, USI^rear) then
    H^rear = true;
if g(SI^front, SI) < −α && g(SI, SI^front) < g(USI, USI^front) then
    H^front = true;
return A = < H_1, H^front, H^rear >;
```

6.4. Overall Algorithm

The overall pipeline for identifying the restoring impact of uplift events is presented in algorithm 1. For an uplift event u with type U', a stressor event e with type S', the overall algorithm is represented as $F : (u, U', e, S') \rightarrow \boldsymbol{A}$.To quantify the restoring impact of uplift events, we first extract uplift events and stressful intervals from the teen's microblogs. All stressful intervals are classified into two sets: the set of stressful intervals affected by uplift events (SI), and the set of stressful intervals impacted by uplift events (U-SI). To judge if SI are statistically different with U-SI, next, the two-sample hypothesis testing method is conducted on the two sets with multi positive and stressful measures (posting behavior, stress intensity and linguistic expressions). To further judge the monotonous restoring intensity of each type of uplift events, the final step comes to comparing SI and U-SI with adjacent intervals, respect to temporal order.

7. Appendix

7.1. Observe the impact of scheduled positive events: students' stress during exam intervals in two situations

To further observe the influence of uplift events for students facing stressor events, we statistic all the stressful intervals Li et al. (2017b) detected surround the scheduled examinations over the 124 students during their high school career. For each student, we divide all his/her stressful intervals into two sets: 1) stressful intervals under the influence of neighbouring uplift events (e.g., *Halloween activity*), and 2) independent stressful intervals. Figure 2 shows five measures of each student during the above two conditions: the *accumulated stress*, the *average stress* (per day), the *length of stressful intervals*, the *frequency of academic topic words*, and the *ratio of academic stress among all types of stress*. For each measure, we calculate the average value over all eligible slides for each student.

7.2. Algorithm 1: Select candidate intervals impacted by positive events

Let the sub-series $w_{<a,b>} = [s'_a, \cdots, s'_b]$ as a *wave*, where $s'_v = vally(w_{<a,b>})$ is the minimum stress value, $s'_p = peak(w_{<a,b>})$ is the maximal stress value during $\{s'_a, \cdots, s'_b\}$, and $s'_a \leq s'_{a+1} \leq \cdots \leq s'_p \leq s'_{p+1} \leq \cdots \leq s'_b$.

7.3. Algorithm2: Identify stressful intervals impacted by positive events.

For each candidate interval, a Poisson based probability model Li et al. (2017b) is adopted to measure how confidently the current interval is a stressful interval. Here a teen's stressful posting rate under stress (λ_1) and normal conditions (λ_0) are modeled as two independent poisson process:

$$Pr[N = n|\lambda_i] = \frac{e^{-\lambda_i T}(\lambda_i T)^n}{n!} \tag{3}$$

where $i \in \{0, 1\}$, $n = 0, 1, \cdots, \infty$. We expect that $\lambda_1 > \lambda_0$, and measure the probability as $P(\lambda_1 > \lambda_0 | N_1, T_1, N_0, T_0)$, where N_1, N_0 are the number of stressful posts, and T_1, T_0 are time duration corresponding to λ_1 and λ_0. Without loss of generality, we assume a Jeffreys non-informative prior on λ_1 and λ_0, and infer the posterior distribution $P(\lambda_1|N_1)$ and $P(\lambda_0|N_0)$ according to Bayes Rule. Thus for current interval I_1 and historical normal interval I_0, the quantified probability $\beta = P(\lambda_1 > \lambda_0 | I_1, I_0) \in (0, 1)$ indicates the confidence whether I_1 is a stressful interval.

7.4. Algorithm3: judge stressful intervals into SI or U-SI

In this part, we filter out two sets of stressful intervals: stressful intervals without the impact of uplift events (SI), and stressful intervals under the impact of uplift events (U-SI). For a detected stressful interval $I =< t_1, \cdots, t_n >$, we consider the temporal order between I and any detected uplift event u happened at time point t_u:

Table 5: Algorithm 1: Select candidate stress intervals impacted by positive events.

A candidate interval $I =< w_1, \cdots, w_i, \cdots, w_m >$ is identified with following rules:
① $s'_1 = 0$, $s'_m = 0$. $\forall s'_j \in \{s'_2, \cdots, s'_{m-1}\}$, $s'_j > 0$.
② Let w_i be the biggest wave in current candidate interval, with $peak(w_i) = \omega$, $\forall$ wave $w_j \in I$, $peak(w_j) <= peak(w_i)$.
③ For w_k before the interval biggest wave w_i , i.e., $\forall w_k \in < w_1, \cdots, w_{i-1} >$, $peak(w_{k+1}) >= peak(w_k)$, $vally(w_{k+1}) >= peak(w_k)$.
④ For w_k behind the interval biggest wave w_i, i.e., $w_k \in < w_i, \cdots, w_m >$, $peak(w_{k+1}) <= peak(w_k)$, $vally(w_{k+1}) <= peak(w_k)$.

- If the uplift event u happens during the stressful interval, i.e., $t_u \in [t_1, t_n]$, the uplift interval I is judged as $I \in SI$.
- For the uplift event happening nearby a stressful interval, we also consider the probability that it conducts impact on the teen's stressful interval. Here the gap between t_u and I is limited to ξ, i.e., if $t_u \in [t_1 - \xi, t_1) \cup (t_n, t_n + \xi]$, then $I \in SI$.

If a stressful interval satisfies none of the above conditions, we classify it into the U-SI set.

7.5. Model 1: quantify significant restoring impact conducted by uplift events

For each teen, three groups of behavioral measures are considered: *posting behavior*, *stress intensity* and *linguistic expressions*, indicated as $\boldsymbol{< D_p, D_s, D_l >}$, respectively. To measure the correlation for each group of positive and stressful behavioral measures, the Euclidean distance is adopted to calculate the distance of structured points in A_1 and A_2.

For each point $\ell x \in A = A_1 \bigcup A_2$, let $NN_r(\ell_x, A)$ be the function to find the r−th nearest neighbor of ℓ_x. Specifically, according to the three group of measures, three sub-functions of $NN_r(.)$ are defined as $PNN_r(.)$, $SNN_r(.)$ and $LNN_r(.)$, corresponding to the teen's posting behaviors, stress intensity and linguistic expressions in each stressful interval, respectively.

For point ℓ_x with posting behavior matrix $\boldsymbol{D_p^x}$, stress intensity matrix $\boldsymbol{D_s^x}$, and linguistic expression matrix $\boldsymbol{D_l^x}$, the r-th nearest neighbor of ℓ_x in each measure is denoted as:

$$
\begin{aligned}
PNN_r(\ell_x, A) &= \{y | min\{\|\mathbf{D}_p^x - \mathbf{D}_p^y\|_2\}, y \in (A/\ell_x)\} \\
SNN_r(\ell_x, A) &= \{z | min\{\|\mathbf{D}_s^x - \mathbf{D}_s^z\|_2\}, z \in (A/\ell_x)\} \\
LNN_r(\ell_x, A) &= \{w | min\{\|\mathbf{D}_l^x - \mathbf{D}_l^w\|_2\}, w \in (A/\ell_x)\}
\end{aligned} \tag{4}
$$

The r-th nearest neighbor considering all three groups of measures is denoted as:

$$NN_r(\ell_x, A) = \{v | min\{a \times \|\mathbf{D}_p^x - \mathbf{D}_p^v\|_2 + \tag{5}$$

$$b \times \|\mathbf{D}_s^x - \mathbf{D}_s^v\|_2 + c \times \|\mathbf{D}_l^x - \mathbf{D}_l^v\|_2\}, v \in (A/\ell_x)\} \tag{6}$$

In this study, we set $a = b = c = 1/3$. Next, let $I_r(\ell_x, A1, A2)$ be the function denoting whether the r-th nearest neighbor is in the same set with ℓ_x:

$$I_r(\ell_x, A_1, A_2) = \begin{cases} 1, & if \ell_x \in A_i \&\& NN_r(\ell_x, A) \in A_i, \\ 0, & otherwise \end{cases} \tag{7}$$

Let $T_{r,n}$ denote the proportion that pairs containing two points from the same set among all pairs formed by $\ell_x \in A$ and its k nearest neighbors:

$$T_{k,n} = \frac{1}{n \times k} \sum_{i=1}^{n} \sum_{j=1}^{k} I_j(x, A_1, A_2) \tag{8}$$

The value of $T_{k,n}$ shows how differently the points in the two testing sets (SI and U-SI) perform in three groups of measures. If the value of $T_{r,n}$ is close to 1, it can be shown that the two underlying distributions $F^{(1)}$ and $F^{(2)}$ for SI and U-SI are significantly different, indicating current uplift events conduct obvious restoring impact on the teens' stress series. Let $\lambda_1 = |A_1|$ and $\lambda_2 = |A_2|$, the statistic value Z is denoted as:

$$Z = (nr)^{1/2}(T_{r,n} - \mu_r)/\sigma_r \tag{9}$$

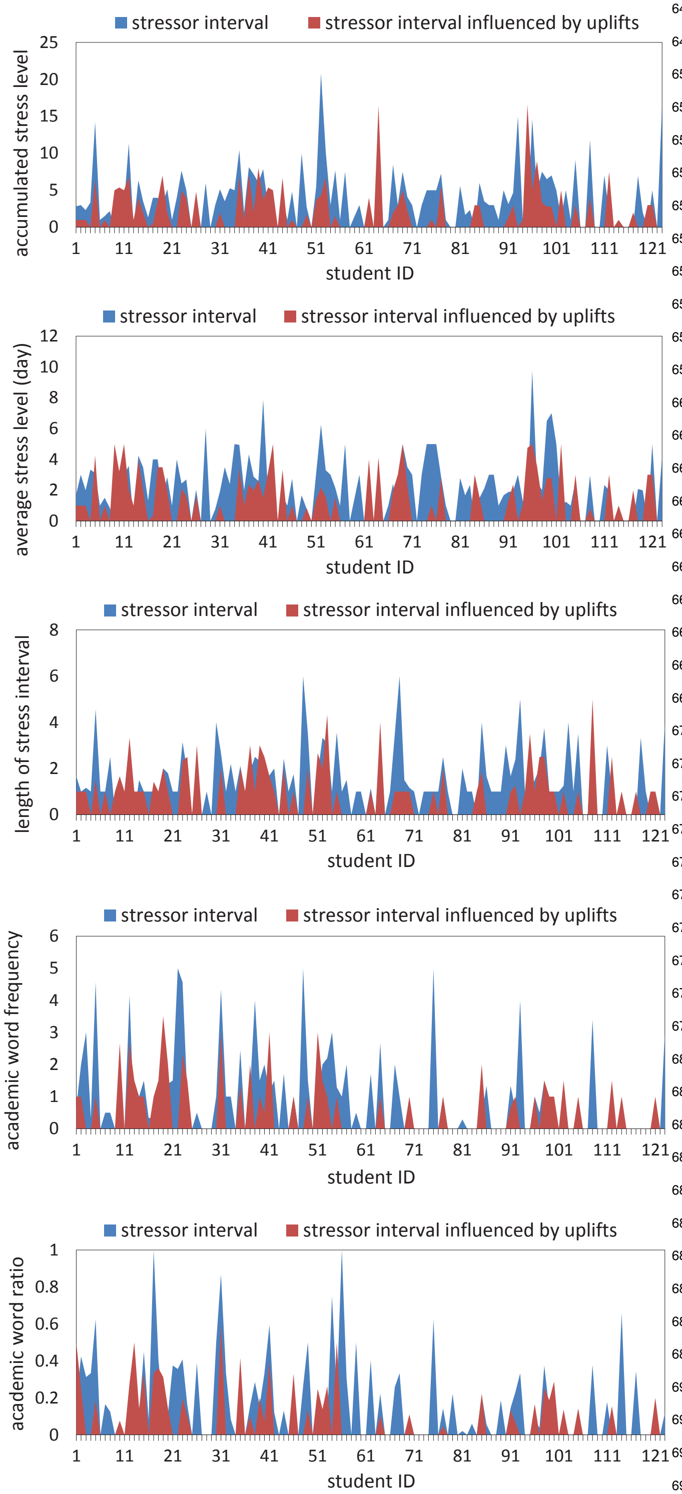
$$\mu_r = (\lambda_1)^2 + (\lambda_2)^2 \tag{10}$$

$$\sigma_r{}^2 = \lambda_1\lambda_2 + 4\lambda_1{}^2\lambda_2{}^2 \tag{11}$$

where μ_r is the expectation and $\sigma_r{}^2$ is the variance of Z. Based on hypothesis test theory Johnson and Wichern (2012), when the size of the testing set (λ_1 and λ_2) are large enough, Z obeys a standard Gaussian distribution.

Thus we judge whether the uplift events have conducted significant restoring impact on the teen's stress series as follows: if $f(SI, USI) = (nr)^{1/2}(T_{r,n} - \mu_r)/\mu_r{}^2 > \alpha$ ($\alpha = 1.96$ for $P = 0.025$), then the hypothesis H_1 is true.

Figure 2: Compare students' stress during exam intervals in two situations: 1) affected by neighboring uplift events (U-SI), 2) no uplift events occurred nearby (SI)



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