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An Agent-Based Social Network Model of Binge Drinking Among Dutch Adults

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Abstract

Binge drinking is a complex social problem linked to an array of detrimental health effects. While binge drinking in youth has been analyzed extensively using traditional methods (e.g., regressions analyses), the adult population has received less attention, and recent work has exemplified the potential for simulations to help scholars and practitioners better understand the problem. In this paper, we used agent-based social network models to test a number of hypotheses on important aspects of binge drinking in a sample representative of the adult Dutch population. In particular, we found that a combination of simple social rules (choosing peers who are similar, being prompted to drink if at least a fraction of them drinks, and incorporating the context) was sufficient to correctly predict the behaviour of half of the binge drinkers and 4 out of 5 non binge drinkers. Furthermore, we used factorial analyses to examine the contribution and combination of hypotheses in predicting the behaviour of individuals, with results indicating that who we interact with may not matter so much as how we interact. Finally, we evaluated the potential for interventions that mediate interactions between people in order to reduce the prevalence of binge drinking and found that the impact of such interventions was non linear: moderate interventions would yield benefits, but stronger interventions may only be of limited further benefit.

Keywords:

Conceptual Exploration, Drinking Motives, Social Influence

Introduction

- 1.1 Alcohol has been estimated to cause 3.2% of deaths worldwide through pathways ranging from cancers (e.g., of liver, mouth, oesophagus) to the behavioural consequences of intoxication, such as injuries due to car crashes (World Health Organization 2002). The harmful effect of alcohol is particularly marked in Europe, for example in terms of its elevated economic burden (Cortez-Pinto 2012). This study uses data collected in the Netherlands, where a significant fraction of the population across all age categories engages in binge drinking (Garretsen et al. 2008).
- 1.2 Numerous studies have demonstrated that peer influences can contribute to drinking (Borsari and Carey 2001; Mercken et al. 2012; Caudill and Kong 2001), for example by synchronizing drinking behaviour with that of a heavy drinking peer (*imitation*) or being persuaded to drink (*pressure*); together, these constitute the influence process. Consequently, addressing the social problem of binge drinking includes approaches aiming at reducing the harmful ways in which individuals influence each other to drink, such as limiting peer pressure to drink, or enabling those pressured to abstain (Haines 1996). This requires that we precisely understand how social interactions contribute to engaging in binge drinking. This has been the object of studies by behavioral scientists, and reviews can be found in (Borsari and Carey 2001; Lewis and Neighbors 2006). In this paper, we examine the extent to which several social processes (i.e., selection and influence processes as described below) can explain the propensity to engage in binge drinking.
- 1.3 Regressions analyses have been the technique of choice for studying the role of social interaction in causing a given behaviour, as reviewed by Sheeran (2002) or recently exemplified by Crutzen et al. (2012) in the case of drinking behaviour. Using this technique, data is collected for independent (e.g., gender, income, previous drinking history) and dependent variables (e.g., being a binge drinker), and correlations are used to infer causal relationships. Our work differs, as we instead aim at illuminating the core dynamics (Epstein 2008) of social influences and binge drinking using an agent-based social network (Hamill and Gilbert 2009). The idea that social influences can be an important contributor and would be adequately modelled using such an approach has been demonstrated in settings ranging from the stock market (Bakker et al. 2010) to chronic diseases (Giabbanelli

et al. 2012, Giabbanelli et al. 2013). In a nutshell, we run simulations based on hypotheses regarding the different ways in which individuals could connect based on independent variables (i.e., selection process) and we compute the value of dependent variables as a result of how individuals interacted with each other (i.e., influence process).

- 1.4 While a few recent studies have also used simulations to explain binge drinking (Ormerod and Wiltshire 2009; Mercken et al. 2012), there are two key differences between their work and ours. First, previous research such as that of Ormerod and Wiltshire (2009) or Mercken et al. (2012) has overwhelmingly been devoted to predicting binge drinking in *youth* (e.g., college students) despite changes in the alcohol industry that have broadened the socio-economic base of drinkers to include far beyond adolescents (Measham and Brain 2005). While a large fraction of young Dutch males engage in binge drinking (19.5% for male aged 15-24), this behaviour is also shared by a significant fraction of male adults of all ages (14.8% for those aged 24-44, and 17.2% for 45-64) (Garretsen et al. 2008). This is similar to data collected in the United States, where 69% of binge-drinking episodes were found to occur in individuals aged 26 years and older (Naimi et al. 2003). From a public health perspective, it should also be noted that continuing to drink during adulthood increases the likeliness of harmful long-term consequences (Beseler et al. 2008; Gotham et al. 1997; Grant and Dawson 1997; Jackson et al. 2002; Perreira and Sloan 2001). Therefore, this work aims at improving our understanding of the social processes underlying binge drinking among adults, which is an important endeavour in light of the paucity of studies compared to youth. Second, we depart from previous methodologies used to examine the extent to which binge drinking can be explained as a social phenomenon. Ormerod and Wiltshire (2009) explored social processes in youth regarding influence but not selection, since an individual's friends were assigned based on macro-level properties (e.g., social structure of the whole population) rather than micro-level choices (i.e., how one chooses friends). In this work, we explore both how individuals choose peers and how they are influenced by them. Mercken et al. (2012) also explored both processes in youth, and our approach shares commonalities with the social network methodology used in their work. Their key contribution was on the dynamic aspects of the network (Steglich et al. 2010) (e.g., how processes play different roles as the participants age) whereas our focus is on the different combinations of influences that can explain binge drinking at one point in time.
- 1.5 Organization of the paper. Our work is based on a real-world dataset of Dutch adults. The dataset is introduced in Section 2, and its variables are used in Section 3 to propose different social processes of selection and influence. In Section 4, we conduct simulations to test the extent to which these hypotheses participate to explaining binge drinking. Results are discussed in Section 5, together with limitations.



Dataset of Dutch adults

- 2.1 Data was collected through the Longitudinal Internet Studies for the Social sciences (LISS) panel^[1], of which the sample and recruitment procedure has been detailed in Scherpenzeel (2011). All LISS data are published online at <http://www.lissdata.nl/lissdata/> and are freely available to academic researchers worldwide. The reference population for the LISS panel is the Dutch speaking adult population permanently residing in the Netherlands. In co-operation with Statistics Netherlands addresses were randomly drawn from the nationwide address frame including individuals who do not have Internet access. These were provided equipment to access the Internet via a broadband connection to ensure representativeness of the sample. Those with small band Internet access were provided with broadband. Members of the LISS panel completed online questionnaires every month for about 15 to 30 minutes in total, and were paid for each completed questionnaire. There was ethics approval for the umbrella project, which was conducted by an external party (CentERdata; <http://www.centerdata.nl/en>). Relevant ethical safeguards were met with regard to the participant confidentiality and consent.
- 2.2 In order to focus on drinking, our previous study selected a random sample of 3,192 respondents among those who reported drinking as of November 2010 (Crutzen et al. 2012). These were all members of the LISS panel. These selected respondents were invited for more in-depth assessments regarding drinking in January 2011, and 2,844 completed the assessment (89.10% response rate). For the purpose of the present study, we selected individuals who answered all questions of the assessment, thereby limiting the sample to 2,837 participants. Demographic information for this final sample is summarized in Table 1.

Table 1: Demographic information of the dataset.

	Participants	Binge drinkers	Average age
Overall	2,837	33.45%	52.00
Male	1,501	39.50%	53.04
Female	1,336	26.65%	50.83

- 2.3 The variables of this dataset used to generate hypotheses in the next Section are the gender, educational level^[2], and most importantly, the frequencies at which individuals drink for various reasons (Table 2), known as *drinking motives* (Cox and Klinger 1988). Drinking motives are the most proximal factors to drinking behaviour under the motivational model of alcohol use (Cox and Klinger 1988). They have been organized into four categories (Cox and Klinger 1988; Cooper 1994) based on whether the motivation to drink comes from the individual or peers (i.e., *source* dimension; internal-external) and whether alcohol is expected

to increase positive feelings or decrease negative ones (i.e., *valence* dimension; negative-positive). In the enhancement category (internal, positive), individuals are internally motivated by effects of drinking such as getting high. The social category (external, positive) stands for the social events that could be a reason for an individual to drink, such as partying. The coping category (internal, negative) sees alcohol as a remedy, for example against depression or worries. Finally, the conformity category (external, negative) represents peer pressure. Individuals were assessed on these categories using the Drinking Motives Questionnaire Revised (DMQ-R) (Cooper 1994), which is the most widely used for drinking motives (Kuntsche et al. 2005) and has been deemed a robust instrument across cultures (Kuntsche et al. 2008). The questionnaire provides 5 questions per category (Table 2). Therefore, the dataset contains 20 variables regarding drinking motives. The distribution of values for these 20 variables is summarized in Figure 1.

Table 2: Variables for drinking motives together with averages in the range [1, 5]

Category	Question: How often do you drink	Average
Enhancement	Because you like the feeling?	2.69
	Because it's exciting?	1.12
	To get high?	1.14
	Because it gives you a pleasant feeling?	2.33
	Because it's fun?	2.17
Social	Because it helps you enjoy a party?	1.77
	To be sociable?	2.20
	Because it makes social gatherings more fun?	1.91
	Because it improves parties and celebrations?	1.82
	To celebrate a special occasion with friends?	2.57
Coping	To forget your worries?	1.21
	Because it helps you when you feel depressed or nervous?	1.23
	To cheer up when you're in a bad mood	1.23
	Because you feel more self-confident or sure of yourself?	1.17
	To forget about your problems?	1.18
Conformity	Because your friends pressure you to drink?	1.04
	So that others won't kid you about not drinking?	1.02
	You drink to fit in with a group you like?	1.06
	To be liked?	1.04
	So you won't feel left out?	1.05

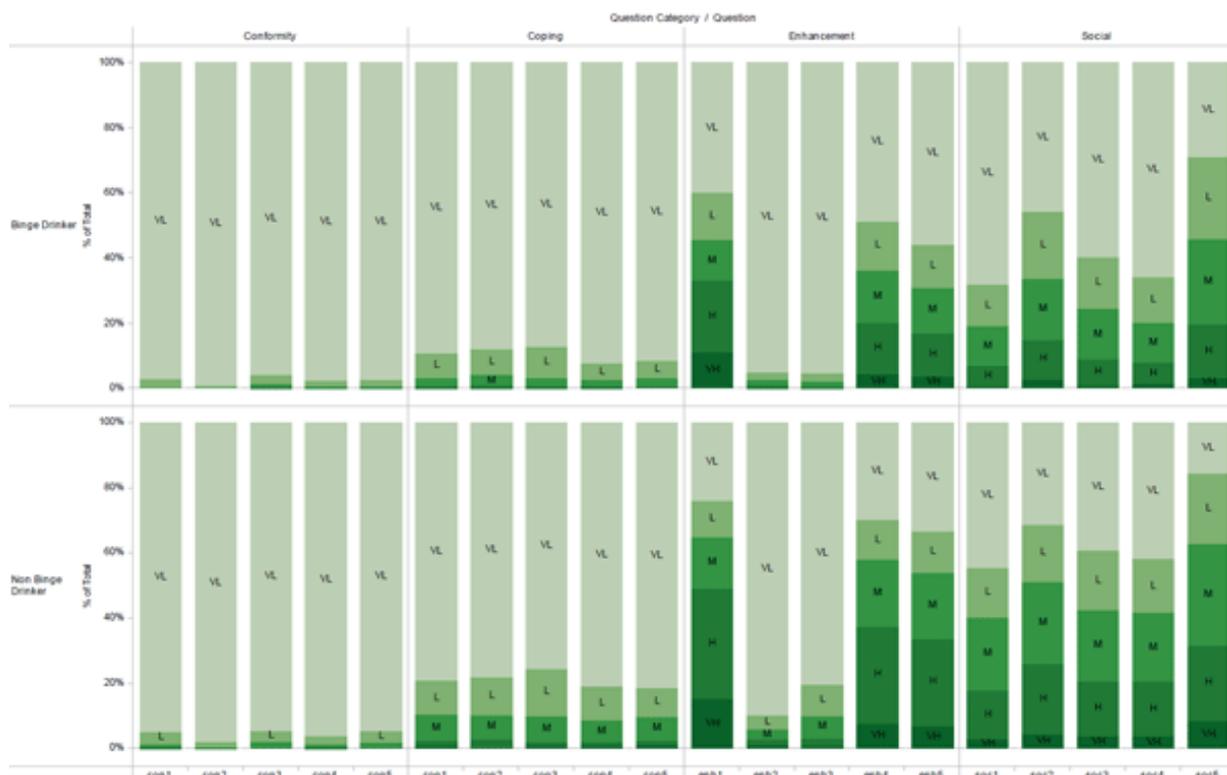


Figure 1. Answers to the 20 questions categorized from Very Low (= 1) to Very High (= 5).

Hypotheses for selection and influence processes

Overview of processes

- 3.1 Two processes have been hypothesised as explaining peer influence on binge drinking. In essence, peer *selection* specifies the type of persons that an individual would befriend, while peer *influence* stands for the effect of peers. These processes are illustrated in Figure 2: a new individual selects peers that are similar (abstracted by a number), and is then influenced by these selected peers (abstracted by a categorical variable).

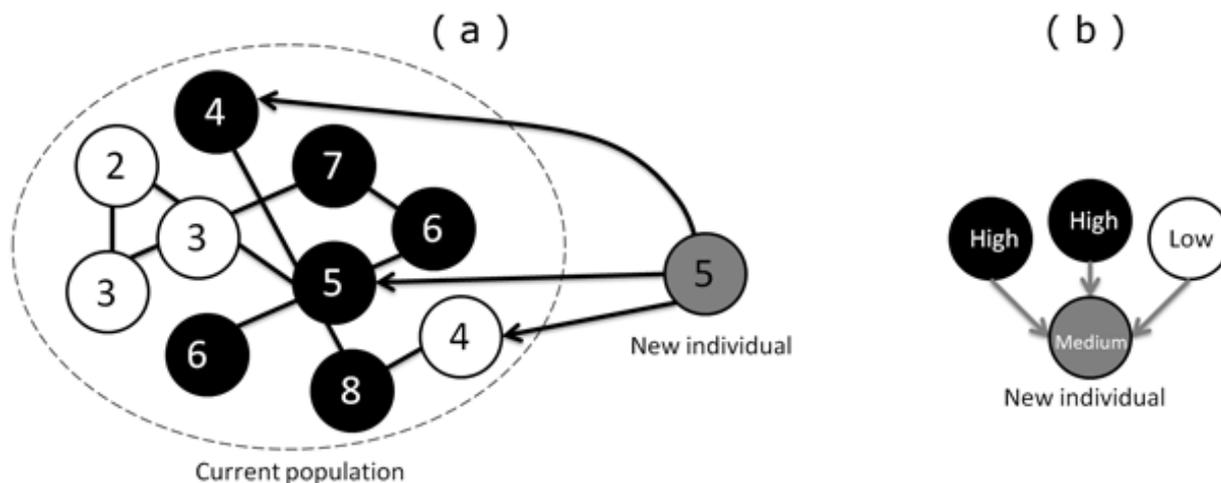


Figure 2. Selection process based on similarity (a) followed by an influence process using a majority vote (b). Binge drinkers are in black while non-bingers are in white.

- 3.2 Evidence was found regarding both processes in youth (c.f. references in (Parra et al. 2007)); a detailed study of the spread of alcohol consumption through a social network can be found in (Phua 2011). Therefore, our hypotheses include both selection and influence processes. A formal example that combines several of these hypotheses is outlined in Algorithm 1.

Selection processes

- 3.3 Under the *random* hypothesis, we assume that one is equally likely to connect to any other peers. Therefore, a set of peers is selected uniformly at random. This is in contrast with the *similarity* hypothesis, whereby the probability to connect two individuals depends on the number of features in common. In our work, the features are drawn from the dataset (Section 2) and consist of the 20 drinking motives as well as gender and education. We further assumed that the similarity between two individuals

depends linearly on the number of features; other assumptions are discussed in Section 5 (paragraph 3).

Influence processes

- 3.4 Models in fields ranging from chronic disease (Bahr et al. 2009) to alcohol (Ormerod and Wiltshire 2009) have commonly abstracted influences to a 'voting process' whereby one would mimic the behaviour taken by at least some fraction of peers. However, a voting process ignores how the context plays role in determining one's behaviour. This context is composed of two antagonist elements. On one hand, *detering* factors (e.g., low social anxiety) can lower the impact of peers on drinking. On the other hand, *promoting* factors (e.g., a tendency of drinking to cope with personal issues) can contribute to facilitating the consumption of alcohol. Besides having the potential to significantly affect behavioural outcomes, the context is also an important target for interventions: we might not be able to change how individuals befriends others or how pressure happens in social circumstances, but individuals' susceptibility to peer influence may be addressed by treating psychological traits such as self-efficacy or social anxiety (Brechtwald and Prinstein 2011).
- 3.5 We investigate the different possibilities for influence processes by separating hypotheses for receiving influence, from hypotheses regarding the use of context. First, the *majority* vote proposes that an individual is assigned the state taken by most peers. Second, the *fractional* vote is a variation of this process in which an individual is assigned the state taken by at least a given critical fraction of peers. This models an imbalance in power between states, such as binge drinkers having a stronger influence towards peers compared to non-binge drinkers. For example, assume that an individual is prompted to engage in binge drinking when at least 25% (i.e., a fraction of $\frac{1}{4}$) of peers are binge drinkers. If the individual is in contact with 10 peers and only 2 of them are binge drinkers then there is no prompt by peers to engage in this behaviour; conversely, if 4 out of 10 peers were binge drinkers then have enough peers to consider that binge drinking is being promoted even if binge drinkers are not the majority of peers.
- 3.6 After one of these two processes has been applied, we can either use its result as the new state of an individual or mediate it using the context. The context can be taken into account via deterring and/or promoting factors. When using deterring factors, an individual's score is given by counting the proportion of drinking motives that have low or very low values (i.e., 1 or 2 on a scale from 1 to 5). If this score achieves at least a given threshold, then the context is deemed strong enough to prevent an individual from engaging in binge drinking. Similarly, promoting factors are measured as the proportion of drinking motives with high or very high (i.e., 4 or 5 on a scale from 1 to 5) and a threshold is applied to determine whether an individual is 'prevented' from being a non-binge drinker.

Algorithm 1: Computing whether an individual is a binge drinker using selection by similarity, fractional influence, deterring and promoting factors.

```
Let  $x$  be a new individual with given gender, educational
achievement, and drinking motives
Connect  $x$  to  $n$  individuals having the same values for more than
 $t_{feature}$  features
If at least a fraction  $f$  of these individuals are binge
drinkers
    If the fraction of 'low' or 'very low' drinking motives is
larger than  $t_{detering}$ 
        Label  $x$  as non-binge drinker
    Otherwise
        Label  $x$  as binge drinker
Otherwise
    If the fraction of 'high' or 'very high' drinking motives
is larger than  $t_{promoting}$ 
        Label  $x$  as binge drinker
    Otherwise
        Label  $x$  as non binge drinker
```



Simulations

- 4.1 The goal of our simulations is to assess the extent to which the hypotheses presented in Section 3 can explain the behavioural outcome (i.e., binge drinking or not) found in the dataset introduced in Section 2. The evaluation uses a standard procedure known as 10-fold cross-validation, in which "the data set is split into 10 parts of approximately equal sizes, and each part is used in turn for testing of a classifier built on the pooled remaining 9 parts" (Kuncheva 2004, p. 19).
- 4.2 Our simulations start with 10% of the 2,837 individuals chosen at random in our dataset, for whom we know whether or not they are binge drinkers. The 90% other individuals are added one at a time, without knowing whether they are binge drinkers. When added to the population, an individual is connected to others based on a given selection process, and the behavioural outcome is computed after applying a given influence process (Algorithm 1). Performances are then evaluated by comparing the computed outcome for the 90% added individuals with what is known in the dataset. When the computed outcome matches the one in the

dataset, we say that the individual has been "correctly classified". Indicators of performances are the percentage of correctly classified binge drinkers, non-binge drinkers, and correctly classified individuals overall.

- 4.3 We test four binary hypotheses on selection (random vs. similarity) and influence (fraction vs. majority vote, with or without preventing factors, with or without deterring factors), leading to $2*2*2*2 = 16$ combinations. Five of them are introduced in the first Section in order of increasing complexity, allowing to explore how various combinations of hypotheses perform. The second Section contains a factorial analysis over the 16 possible combinations analysing the interplay of different hypotheses. Our results suggest that the context plays an important role in predicting binge drinking, and the potential to capitalize on it to address binge drinking is explored in the third Section.

Predictive ability of combined hypotheses

- 4.4 Research does not currently provide data on the number of individuals with whom one may drink. Therefore, performances are reported as a function of that number, which was set to vary from 5 to 20. Furthermore, to account for the randomness of selection processes, performances are reported as the average across 100 simulation runs. Finally, we optimised parameters for each combination of hypotheses, which allows evaluating the best potential of the hypotheses as in (Ormerod and Wiltshire 2009). This resulted in choosing to befriend those who are similar on at least one third of the variables (similarity selection process), being prompted to engage in binge drinking if at least one fourth of peers are binge drinkers (fractional influence process), being 'protected' from binge drinking if three fourth of drinking motives are low or very low, and being a binge drinking if at least one tenth of drinking motives are high or very high.
- 4.5 A naive combination of hypotheses would be to state that individuals select peers at random, and that they take the behaviour found in most of their peers. Since most individuals in a population are *not* binge drinkers, this tends to result in every new individual classified as a non binge drinker. Thus, all non-binge drinkers are correctly classified while all binge drinkers are incorrectly classified. However, the overall performance appears satisfactory, since about two thirds of the dataset contains non-binge drinkers. Therefore, it would be misleading to judge of the extent to which given processes explain binge drinking solely by looking at the overall number of individuals who were correctly classified: the balance between detecting non-binge drinkers and binge drinkers must be taken into account.
- 4.6 Changing the influence process from a majority vote to taking the state of at least a given fraction of peers may only reverse the issue by classifying almost everyone as a binge-drinker, as showed in Figure 3(a). Since the idea of 'blindly' assigning a particular individual to the state taken by most peers does not prove successful, we instead consider the role of the context. In Figure 3(b), we consider how binge drinking can be promoted if there are enough peers engaged in this behaviour (i.e., the "fraction" process) *but* also that deterring factors can prevent individuals from engaging in it. The result of using this method is that individuals can be more accurately classified as binge drinkers at the price of a small decrease in the accuracy of classifying non-binge drinkers, while still achieving the same overall performance as the majority vote discussed earlier. This exemplifies the idea of balance in a complex social problem: a set of hypotheses can provide a valuable insight into a situation where the gain in classifying one class is greater than the loss in classifying another.
- 4.7 Keeping the fractional process and deterring factors but selecting peers based on similarity (i.e., peers with whom we share at least one third of values) yields almost identical results, as pictured in Figure 3(c). However, the addition of promoting factors produces the more desirable balance displayed in Figure 3(d). In this situation, almost half of binge drinkers and 4 out of 5 non binge drinkers are correctly identified. This is the most accurate result across the 16 possible combinations.

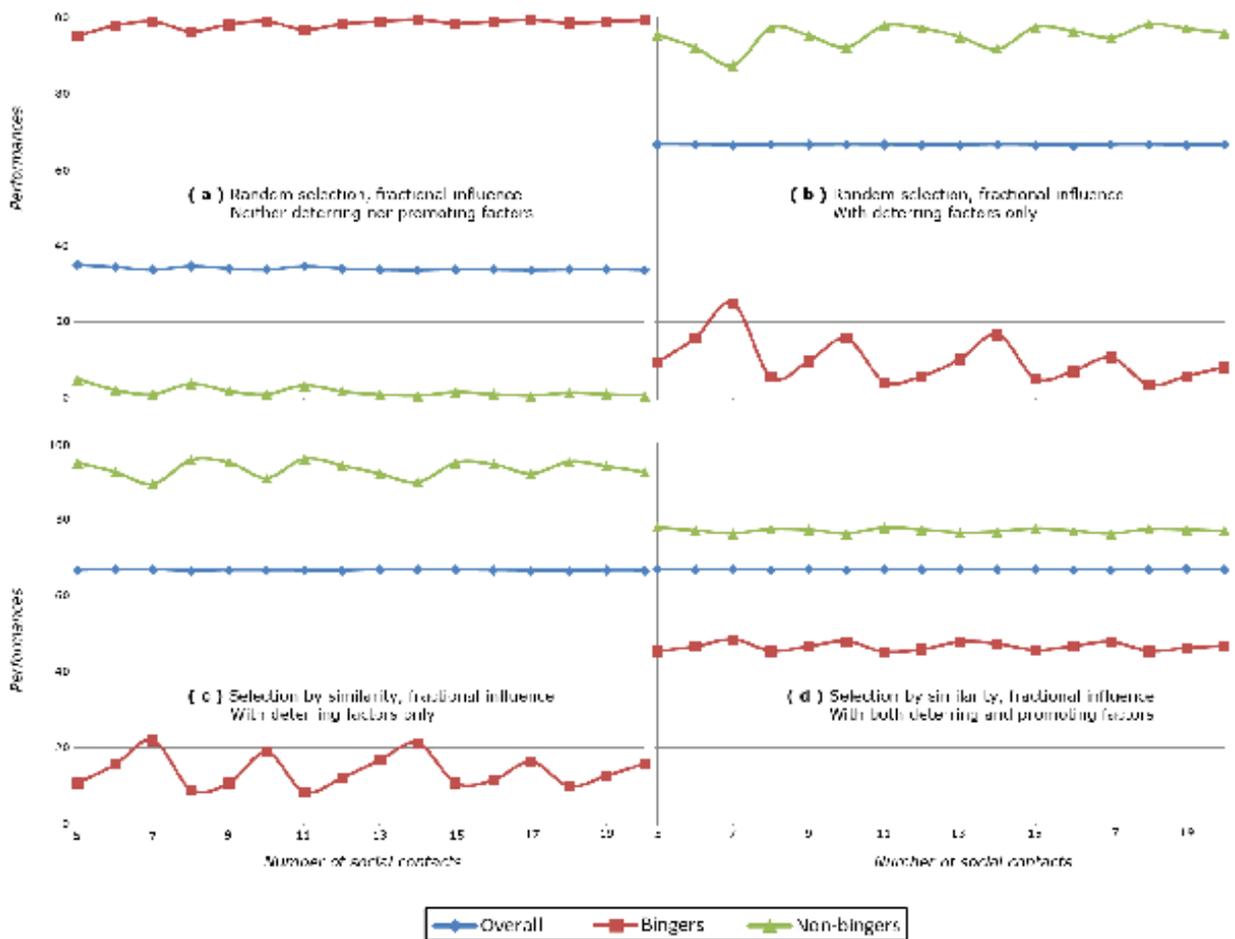


Figure 3. Performances of four combinations of selection and influence processes as a function of the number of social contacts. *Color online.*

Interactions between hypotheses and impact

4.8 In order to analyze how different hypotheses contribute to the predictions, we used a factorial analysis (Jain 2002). In a factorial analysis, an experiment relies on a combination of assumptions, such as "random selection with majority vote and no moderators" or "selection by similarity with majority vote and moderators". As we have 4 hypotheses ('voting' process, deterring and promoting factors, selection) each with two choices, assessing all combinations leads to $2^4=16$ experiments. Each experiment was replicated three times, in order to also measure the variability due to randomness. Results are shown in Figure 4 for each of the three indicators of performances, using 16 as the set number of social contacts. Factorial analyses were also conducted for 9 and 13 social contacts, and they yielded results similar to the one performed for 16 edges. Results suggest that the choice of a selection process plays a marginal role compared to influence, which is further discussed in the next Section.

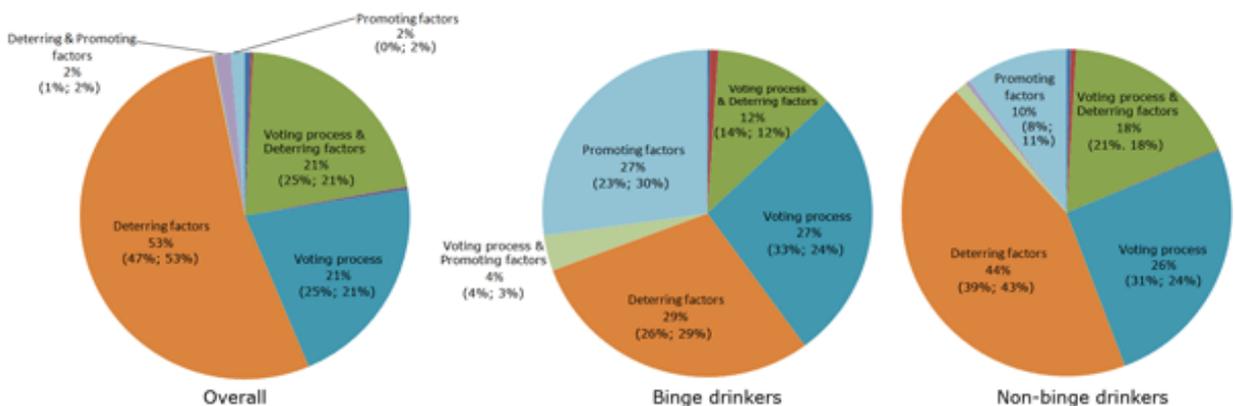


Figure 4. Contribution of hypotheses and their interactions to performances for 16 social contacts. Contributions within parentheses were obtained for 13 and 9 social contacts respectively.

Potential of intervening on the context

4.9 The importance of the deterring and promoting factors discussed in the previous Section (Figure 4) raises questions over the potential of intervening on them to lower the prevalence of binge drinking. We investigated that potential through the following three step process:

- Run a simulation to label all individuals, using the most accurate combination of selection by similarity, fractional vote, promoting and deterring factors as in Figure 3(d).
- For those individuals who were correctly identified as binge drinkers (i.e., those whose situation can be explained by the simulation), change the impact of their promoting and deterring factors and evaluate whether they are still binge drinkers.
- Evaluate the impact of the virtual intervention by measuring the proportion of individuals who were initially correctly identified as binge drinkers but no longer engage in binge drinking as a result of the change in context.

4.10 In the most accurate simulation setting, promoting and deterring factors took the values of 0.75 and 0.1. Consequently, interventions' impacts were estimated by varying these values to 0 (more pressure not to drink) and 1 (less pressure to drink) respectively, by steps of 0.05. For each combination of values, the process above was repeated 1000 times to compensate for the variability caused by intervening on a subset of the population. Results are displayed in Figure 5. Results are not intended to provide an accurate estimate of actual interventions: they are only indicative of trends in the prevalence of binge drinking. In particular, they highlight that interventions have a nonlinear impact on binge drinking: small changes in either deterring or promoting factors may be sufficient to yield noticeable consequences in the population (Figure 5 bottom left), and the added value of interventions decreases as they are stronger (Figure 5 top right).

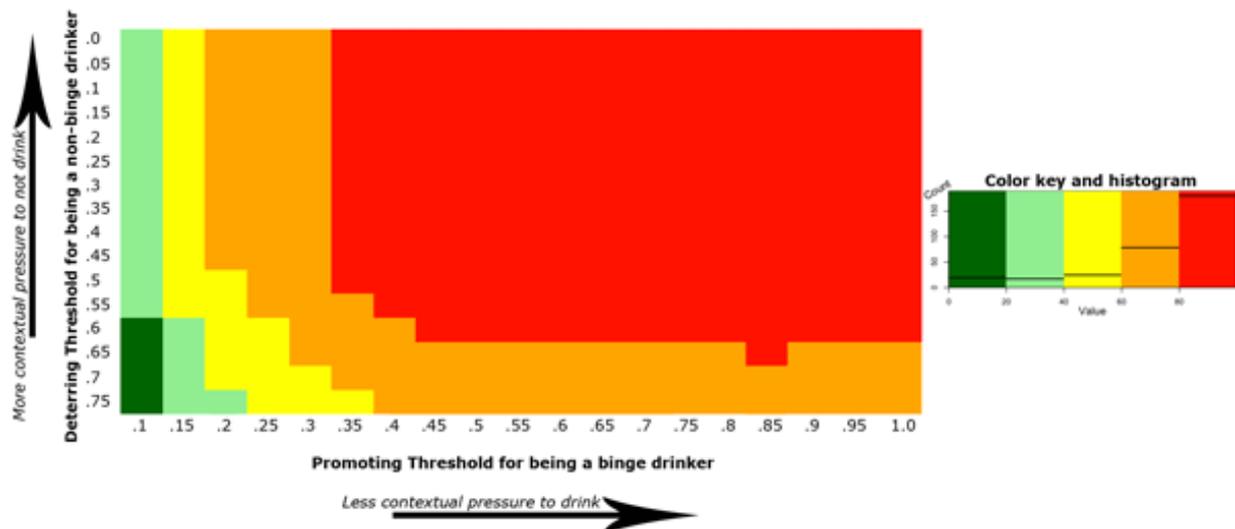


Figure 5. Heatmap of the reduction in the prevalence of binge drinking as the contextual pressure to drink is lowered (horizontal axis) and the contextual pressure to not drink is increased (vertical axis).



Discussion and conclusions

- 5.1 A significant fraction of the European population engages in binge drinking (Garretsen et al. 2008) despite an array of adverse health effects (World Health Organization 2002) and burdening economic consequences at the country level (Cortez-Pinto 2012). Policy measures typically aim at limiting access to low cost alcohol, for example by increasing prices or changing urban regulations in order to either lower alcohol outlet density or limit opening times for alcohol-serving venues (Weitzman et al. 2003). While such initiatives can contribute to the reduction of binge drinking behaviour (Nelson et al. 2005), cultural and individual differences are important in explaining that behaviour (Measham and Brain 2005). While some policies have attempted to combat drinking by 'demonizing' certain groups as a "small and anti-social minority", research suggests that a significant fraction of the population may engage in drinking precisely for social reasons (Measham and Brain 2005). Consequently, interventions on peer influence could be a valuable component of a comprehensive approach to reducing binge drinking (Haines and Spear 1996). This raises two questions: which mechanisms shape peer influence, and what do these findings suggest for interventions?
- 5.2 In this paper, we used simulations to answer these two questions. While this approach has been used previously to investigate binge drinking in youth (Ormerod and Wiltshire 2009; Mercken et al. 2012), the adult population has received less attention despite the health issues resulting from continuing to drink in adulthood (Beseler et al. 2008; Gotham et al. 1997; Grant and Dawson 1997; Jackson et al. 2002; Perreira and Sloan 2001) and the increased targeting of adults by the alcohol industry (Measham and Brain 2005) (Section 1). Therefore, this paper contributes to the relatively unexplored area of using simulations to understand peer influence on binge drinking in adults. We developed an agent-based social network model to explore how selection and influence processes (Section 3) explained binge drinking in a sample representative of the adult Dutch population (Section 2). Our three key findings were obtained through simulations (Section 4).
- 5.3 First, we found that a combination of simple social hypotheses (choosing peers who are similar, being prompted to drink if at least a fraction of them drinks, and incorporating the context) was sufficient to correctly predict the behaviour of half of the binge drinkers and 4 out of 5 non binge drinkers. This highlights the potential of simulations to complement traditional approaches in understanding binge drinking. Furthermore, this suggests that the importance of the social context in determining binge drinking is in line with current research proposing to take into account the context to measure (c.f., the recent review by Kuntsche and Labhart (2012)) and observe (Kuendig and Kuntsche 2012) drinking behaviour. Second, we used factorial analyses to test the

validity of these hypotheses when confronted with the data. Our results indicated that *who* we interact with may not matter so much as *how* contextual factors shape that interaction, since such factors consistently showed to be more important contributors to predicting binge drinking in the factorial analysis of our experiments (Section 4, Figure 4). As highlighted in previous research, the importance of selection versus influence processes changes over the life course (Mercken et al. 2012). Therefore, it is possible that influence processes play a significant role in the adult Dutch population. However, this should be further investigated by refining the hypotheses used to account for selection processes. Third, the importance of influence processes led us to test virtual interventions that attempted to change how much individuals influence each other in order to reduce the prevalence of binge drinking. Results suggested that moderate interventions could yield benefits, but stronger interventions may only be of limited further benefit. While a cost-analysis would be required to rigorously inform policies regarding implementation of interventions, these results nonetheless point to the important nonlinear aspect of an intervention on influence, as the benefits do not follow linearly from the strength of the intervention. While this nonlinear aspect is not currently explained by social psychology, where the topic has not yet been addressed in depth, it confirms approaches used in the development of interventions (e.g., Intervention Mapping by Bartholomew et al., 2011). Indeed, these approaches often use an array of behaviour change methods and an underlying assumption is that the interaction between these methods results in an intervention that is likely to change behaviour, instead of expecting the benefits to follow linearly from one method only.

5.4 While our sample was representative of Dutch adults who drink alcohol, one should be cautious when generalizing our findings to other contexts. For example, the culture surrounding drinking is different in North America than in Europe (Kuntsche et al. 2010), and also within Europe between different countries (Kuntsche et al. 2006). Refining our model in terms of both individual factors (e.g., cognitions, personality, genetics) and environmental factors (e.g., drinking situations, availability of alcohol) (Hawkins et al. 1992) would be a valuable step forward in generalising our findings to different settings. One example of this refinement would be to assign different weights to drinking motives when assessing one's context, since binge drinkers and non-binge drinkers can differ more significantly on some motives than others (Figure 6). Doing so would require optimization techniques in order to find the best combination of weights. Another promising approach for refining our model focusing on peer influence would be to combine it with an agent-based model such as that of Fitzpatrick and Martinez that accounts for geographical aspects (Fitzpatrick and Martinez 2012).

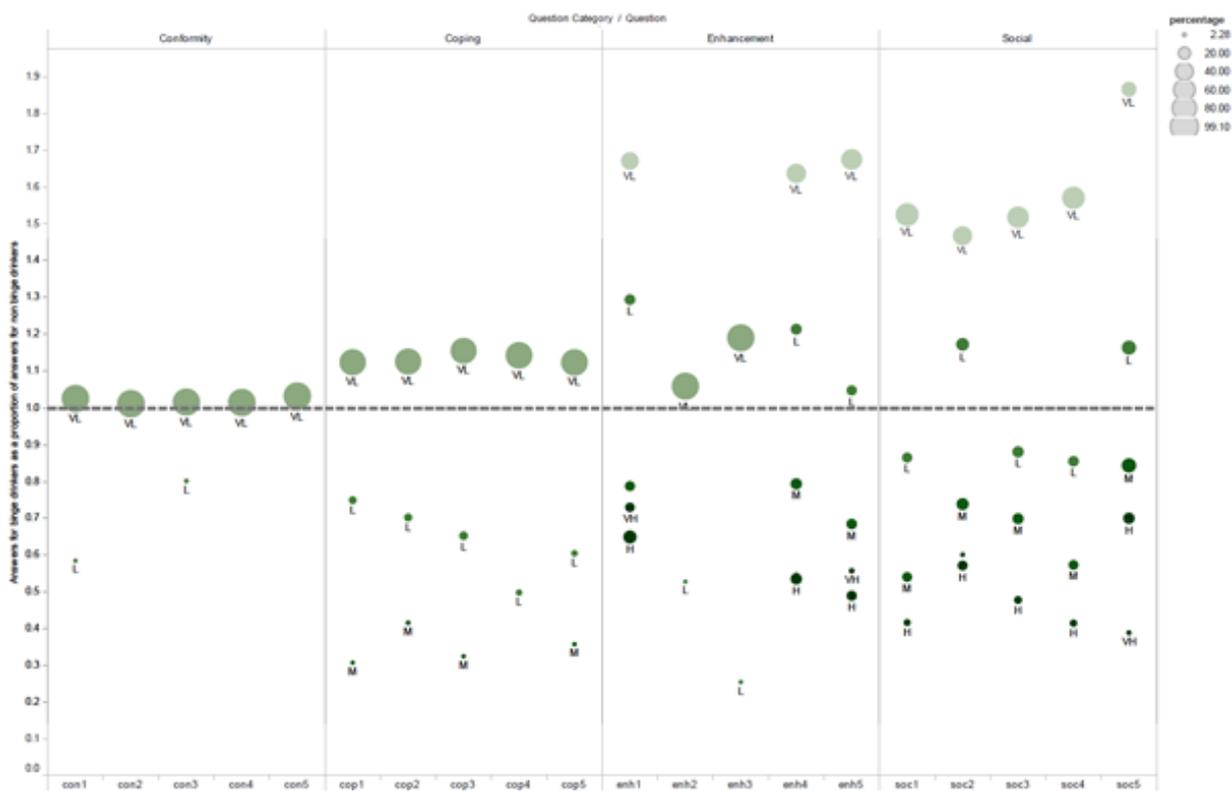


Figure 6. Proportions of answers given by binge drinkers compared to non-binge drinkers. The reference line (1.0) shows answers endorsed at the same proportion in the two groups; answers above this line are more frequent for binge drinkers, and answers under the line are less frequent. Sizes are indicative of the percentage of drinkers having endorsed that response, from 2.28% (small circle) to 99.10% (large circle).



Appendix

I. Model Components

Table A1: Components abstracted in Algorithm I (Section III) and Appendix II.

Component	Meaning	Operationalization
t_{feature}	Fraction of features that must be shared when connecting with individuals (similarity hypothesis, Section 3.2)	.3
f	Fraction of peers who must be binge drinkers in order to promote bingeing (fractional hypothesis, Section 3.3)	.28
t_{detering}	Fraction of drinking motives that are either 'low' or 'very low' in order to be protective (detering factors, Section 3.3)	.23
$t_{\text{promoting}}$	Fraction of drinking motives that are either 'high' or 'very high' and promote bingeing (promoting factors, Section 3.3)	.1
n	Number of individuals that a newcomer is connected to (Section 4.1)	From 5 to 20

II. Pseudo-code of Simulation

- 6.1 The population is represented as a graph, where nodes stand for individuals and they are connected by edges when they influence each other. Each individual has a set of features, which is composed of demographic information (Table 1), drinking motives (Table 2), and drinking status.
- 6.2 First, 10% of individuals from the dataset are added to the population (lines 1-8). These individuals will be used as the core population, that is, their known drinking status will be used to infer the drinking status of the remaining 90%, which will serve to evaluate the accuracy of the selected hypotheses. Consequently, the drinking status of the core population is directly copied from the dataset.
- 6.3 Second, the other individuals are added to the dataset and connected to core members based either on similarity or uniformly at random (lines 9-15). Given the incremental nature of the procedure, a new individual is only connected to individuals with a binge drinking status, either known from the dataset or inferred. We count the number of binge drinkers and non binge drinkers among those connections (lines 16-17), and then examine whether there is a sufficient number of binge drinkers in order to prompt engagement in this behaviour (line 18). If so, the individual is labelled as a binge drinker unless the context acts in a sufficiently strong manner against it (lines 19-22). Otherwise, the individual is labelled as a non-binge drinker unless the context promotes binge drinking in a sufficiently strong manner (23-27).
- 6.4 Our implementation in Java using Jung for the graph structure is available upon request.
 1. Data \leftarrow Dataset containing all available information on all participants
 2. G \leftarrow Empty graph to contain the population
 3. FractionCore \leftarrow 0.1 //fraction of participants for which we use the known status
 4. For $i = 0$ to $0.1 * \text{size}(\text{Data})$: // adds the core population
 5. Select a participant P at random from Data
 6. Add to P all features from the dataset
 7. Flag P as being part of the core population
 8. Adds P to G
 9. For $i = 0$ to $0.9 * \text{size}(\text{Data})$: // adds the individuals for whom we'll infer the status
 10. Select a participant P at random from Data
 11. Add to P all features from the dataset but drinking status
 12. If we use the similarity hypothesis
 13. Connect P to n similar individuals sharing $> t_{\text{feature}}$ values
 14. Otherwise
 15. Connect P to n individuals uniformly at random
 16. Let B be the number of contacts of P who are binge drinkers
 17. Let nonB be the number of contacts of P who aren't binge drinkers
 18. If (we use the majority hypothesis and $B \geq \text{nonB}$)
 - or (we use the fractional hypothesis and $B \geq f * \text{number contacts}$)
 19. Label P as a binge drinker
 20. If we use deterring factors
 21. If t_{detering} drinking motives are 'low' or 'very low'
 22. Label P as a non-binge drinker
 23. Otherwise
 24. Label P as a non-binge drinker
 25. If we use promoting factors
 26. If $t_{\text{promoting}}$ drinking motives are 'high' or 'very high'
 27. Label P as a binge drinker
 28. Adds P to G



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Notes

¹ http://www.lissdata.nl/dataarchive/study_units/view/1

² Divided into three categories: low (primary school/junior high school), intermediate (senior high school/junior college), and high (college/university).



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