Supplementary materials

Supplementary materials to protocol for game based learning study.

# Contents:

## Text

## Network MR intervention scoring

## Figures

## Tables

## Power calculation

## Learning assessment

## Intended learning outcomes

Text

# Supplementary text 1. Network MR intervention scoring

Discovering the optimal intervention using Network MR

Network MR is performed to discover the optimal interventions. The network MR method is detailed in full in Moreno-Stokoe and colleagues. The MiRANA JavaScript library (Moreno-Stokoe, Haworth, Davis) includes a method for conducting Network MR which can be used to estimate the effects of interventions. It is used here to score interventions, and will be detailed in full in the original paper describing the development of the game where it was also applied (Moreno-Stokoe, Haworth, Davis). Application of Network MR will discover all possible interventions and estimate their effects on all public health traits.

Scoring effects

The magnitude and valence of each individual effect that an intervention has on each trait in analysis will be used to score each individual effect.

The magnitude is the amount the prevalence of the trait will be changed by the effect (i.e., the beta weight β):

The valence refers to the amount of ‘good’ that the effect will have considering whether the trait is good or not. Interventions which have good effects (such as reducing smoking) receive positive scores but interventions which have a bad effects (such as reducing wellbeing) receive negative scores. To score this, each trait in analysis was categorised whether it had a good, neutral, or bad effect on health:

|  |  |  |
| --- | --- | --- |
| **Bad** | **Neutral** | **Good** |
| Depression | Coffee intake | Exercise |
| Worry | BMI\* | Sleep |
| Loneliness | Eveningness | Wellbeing |
| Insomnia |  | Education |
| Neuroticism |  | Intelligence |
| Alcohol |  | Socialising |
| Smoking |  |  |
| Heart disease |  |  |
| Diabetes |  |  |

*Note:* \* = Changes in BMI can be healthy or unhealthy depending on the starting BMI

A valence multiplier (*vm*: see below) determined whether the score is positive or negative based on whether it effects a good or bad trait.

|  |  |  |  |
| --- | --- | --- | --- |
|  | ***vm* value depending on category of trait** | | |
| **Effect magnitude** | **Good trait** | **Bad trait** | **Neutral trait** |
| >0 (an increase) | 1 | -1 | 0 |
| <0 (a decrease) | 1 | -1 | 0 |

The valence and magnitude of an effect were multiplied to give its score, broadly representing the amount of ‘good’ it did.

*Worked example*

For example, an intervention reduced smoking by 5 units would be scored thusly:

**Effect score**

Formula

Calculation

Scoring interventions

Interventions were given total scores in two ways.

First, its primary effect was scored. Interventions were designed by participants to achieve an objective. For example, the first question asked participants to: “Select intervention(s) to **most increase wellbeing,** whilst most improving the overall physical and mental health of the network”. The intervention’s effect score on the objective trait (*OT*) gave the primary effect score.

Second, its side effects were scored. Interventions can have many effects, such as reducing smoking as well as reducing heart disease. Effect scores were calculated for every trait in analysis that the intervention effected. These were summed to give an estimation of the total ‘good’ done by the intervention. This comprised the side effect score.

*Worked example*

For example, consider an interventions which reduces smoking, the objective trait, by 5 units and has a side-effect which increases wellbeing by 5 units as well. This would be scored as so:

**Primary effect score**

Formula

Calculation

**Side effect score**

Formula

Calculation

\* 1

Total scores

Scores will be ranked. All possible interventions will be ranked in their primary effect and side effect scores (separately). Participants will score their ranking. For example, an individual who selects the optimal intervention would receive a rank of 1, and an individual who selects the 5th most optimal intervention would receive a rank of 5.

Individuals will receive total primary scores simply by summing their primary effect scores for all 4 questions.

Total side effect scores will be summed in the same manner.

Tables

# Supplementary table 1. Power calculation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Assessment score** | | | **Sensitivity** | | **Required n participants** | |
| **Control group mean\*** | **Standard deviation\*** | **Experimental group mean** | **Power** | **Alpha** | **Per group** | **Total** |
| 13.84 | +/- 1.77 | 14.84 | 80% | 0.05 | 49 | 98 |
| 0.01 | 73 | 146 |
| 0.001 | 107 | 214 |
| 90% | 0.05 | 66 | 132 |
| 0.01 | 93 | 186 |
| 95% | 0.05 | 81 | 162 |
| 0.01 | 112 | 224 |

*Note:* Power calculation for sample size required to observe a meaningful difference in learning outcomes between groups(1 point in the assessment ≈ 1 Intended Learning Outcome). \* = Estimation of priors from pilot testing (n=6).

# Supplementary table 2. Learning assessment

Note: Correct answers in green. All correct answers scored 1 point unless otherwise stated. Numbers in brackets are response codes used for scoring in analysis. Question numbers were incorrectly auto-generated by Qualtrics, were not shown to participants and were not used in analysis.

Start of Block: Area of competency 1

Q47 Select from the list below all the traits present in the network

* Education (1) – 0.2 score
* Heart Disease (2) – 0.2 score
* Wellbeing (3) – 0.2 score
* Eveningness (4) – 0.2 score
* Diabetes (5) – 0.2 score
* Coffee intake (6) – 0.2 score
* OCD (7)
* Public transport use (8)
* Phone use (9)
* Videogaming (10)
* Weight (11)
* Diet (12)
* Drug use (13)
* Social anxiety (14)

Q48 Does insomnia share a **direct** relationship with eveningness?

* Yes (1)
* No (2) – 1 score

Q98 Please indicate how different arrow colors in the visualisation represent how different relationships affect the prevalence of traits:

|  |  |  |
| --- | --- | --- |
|  | Increases (1) | Decreases (2) |
| Red arrows represent... (1) | 0.5 score |  |
| Blue arrows represent... (2) |  | 0.5 score |

Q49 For the next few questions please consider the **direct** relationship between **coffee intake** and **intelligence**

Q50 What is the **direction** of this relationship?

* Intelligence affects coffee intake (1)
* Coffee intake affects intelligence (2)

Q51 Compared to the effect size of other effects in the network, how **large** is this effect? (Remember the visualisation does not show relationship strengths)

* Larger than average (2)
* Smaller than average (3)

Q52 Is this relationship responsible for an increase or decrease?

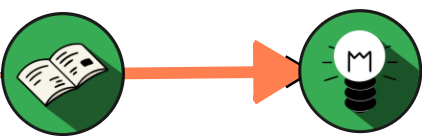
* The effect is responsible for an increase (1)
* The effect is responsible for a decrease (2)

End of Block: Area of competency 1

Start of Block: Area of competency 2

Q86 On the picture below please click on the **trait**which is responsible for a change in the other (the color of the traits is not important for this question):

Not scored



Q53   
Imagine that a fast food restaurant opened up and people started going there so much that they put on weight. This would **increase** their BMI. What effect would this have on **smoking**? (Remember the visualisation does not show relationship strengths)

* Smoking would increase by a relatively large amount (1)
* Smoking would increase by a relatively small amount (2)
* Smoking would reduce by a relatively large amount (3)
* Smoking would reduce by a relatively small amount (4)

Q54   
Would either of the following public health interventions directly increase exercise? Please consider only the immediate **direct** effects of interventions.

* Increasing intelligence would increase exercise (1)
* Increasing education would increase exercise (2)
* No, neither of the interventions above would increase exercise (4)

Q55 Which intervention would **most reduce** heart disease directly? Please consider only the immediate direct effects of interventions.

* Increasing exercise (1)
* Reducing diabetes (2)
* Increasing education (3)

End of Block: Area of competency 2

Start of Block: Area of competency 3

Q56 Would the effects of an intervention to **increase education** be on the general mental and physical health of the population? For the purposes of this question please treat increases in coffee intake, BMI, eveningness, smoking, neuroticism as **bad** even if this is not intuitive to you (you can see whether traits are good/bad by using the Trait key under the help menu of the visualisation)

* Its effects would be only good (1)
* Its effects would be mixed (3)
* Its effects would be only bad (4)

Q58 Which trait causes the **greatest** effects on other traits in the network? (Remember the visualisation does not show relationship strengths)

* BMI (1)
* Education (2)
* Intelligence (3)
* Depression (4)

End of Block: Area of competency 3

Start of Block: Area of competency 4

Q88 Reflecting on your experience with the interactive visualisation or game software please drag the bar below to indicate how much you found it easy to use

Item not scored

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Very difficult to use | Somewhat difficult to use | Somewhat easy to use | Very easy to use |

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

|  |  |
| --- | --- |
| Usability (1) |  |

Q60   
Imagine a scenario where students go to University. One might expect that education **and** alcohol consumption would **both increase**. What would be the combined **direct** effects of this on eveningness? Please consider only the immediate direct effects of interventions.

* Increasing education and alcohol consumption would both increase eveningness (1)
* Increasing education and alcohol consumption would both decrease eveningness (2)
* The effects of increasing education and alcohol consumption would cancel out and there would be little/no effect (3)

Q61 Select the combination of interventions whose direct effects would most **increase**wellbeing.  Please consider only the immediate **direct** effects of interventions.

* Reduce neuroticism, depression, and insomnia (1)
* Reduce worry, depression, and insomnia (3)
* Increase exercise and reduce eveningness (4)

End of Block: Area of competency 4

Start of Block: Area of competency 5

Q95 Click on the trait(s) below which would be **increased** by an intervention on education (please ignore the colours of the traits for this question)

Not scored



Q62 Imagine that Universities were closed and the students just went home. This would **reduce** education. Given the example of the relationship between education and intelligence (shown above), what would happen if education was **reduced**?

* Insomnia would increase (1)
* Insomnia would not be affected (2)
* Insomnia would decrease (3)

Q63 What effect would **reducing**depression have on worry?

* It would have no effect (1)
* It would reduce worry (2)
* It would increase worry (3)

End of Block: Area of competency 5

Start of Block: Area of competency 6

Q64 When considering the whole network of effects, **including all indirect effects**, does depression have an effect on coffee intake?

* Yes (1)
* No (2)

Q97 For the next two editions please consider the scenario: Imagine that a new brewery opened up and people started drinking **more** alcohol.

Q65 For this question we would like you to focus on only two of the effects of increasingalcohol consumption: it **increases** BMI and **reduces** education. Education then has a knock-on effect on BMI. We would like you to identify what this effect is and use this to estimate the combined overall effects on BMI:

* Increasing alcohol and reducing education would both increase BMI (1)
* Increasing alcohol and reducing education would have opposing effects on BMI which would cancel out so overall there would be no effect (2)
* Increasing alcohol and reducing education would both reduce BMI (3)

Q68 For this question we would like you to focus on two **different**effects of increasing alcohol consumption: it**reduces** eveningness and **reduces** education. Education then has a knock-on effect on eveningness. We would like you to identify what this effect is and use this to estimate the combined overall effects on eveningness:

* Increasing alcohol and reducing education would have opposing effects on eveningness which would cancel out so overall there would be no effect (1)
* Increasing alcohol and reducing education would both reduce eveningess (2)
* Increasing alcohol and reducing education would both increase eveningness (3)

Q66 True or false: 'The size of effects decreases for each step in a pathway since each step is propagating a smaller proportion of prevalence change'

* True (2)
* False (3)

Q67 Select the intervention which would indirectly **increase** wellbeing:

* Increasing depression (2)
* Decreasing loneliness (3)
* Increasing insomnia (4)

Q69 Consider what would happen if depression **increased.** What is the furthest point in the network which will be affected by this?

* Its effects will reach wellbeing (1)
* Its effects will reach insomnia (2)
* Its effects will reach coffee intake (3)

Q70 If an intervention **reduced**depression, what would be the **biggest**source of change to wellbeing?

* The direct effect of depression on wellbeing (1)
* The indirect effect of worry on depression (2)
* They would both be equal (3)

End of Block: Area of competency 6

Start of Block: Area of competency 7

These items are scored separately to the rest of the assessment. See supplementary text 1 for Network MR scoring method.

Q53 In the next questions you will be asked to design interventions to achieve goals. Please hold the 'ctrl' / 'cmd' key to select multiple interventions (up to 3). You may need to scroll down to view all of the trait options available in each answer box.  
  
  
Remember the visualisation does not show relationship strengths.

Q72 Select intervention(s) to **most increase wellbeing,** whilst most improving the overall physical and mental health of the network.

* Increase eveningness (1)
* Reduce alcohol (2)
* Increase intelligence (3)
* Increase exercise (4)
* Increase coffee consumption (5)
* Increase socialisation (6)
* Reduce BMI (7)
* Reduce diabetes (8)
* Reduce heart disease (9)
* Reduce smoking (10)
* Increase education (11)
* Reduce insomnia (12)
* Reduce loneliness (13)
* Reduce neuroticism (14)
* Reduce depression (15)
* Reduce worry (16)

Q73 Select intervention(s) to **most increase socialisation,** whilst most improving the overall physical and mental health of the network.

* Increase eveningness (1)
* Reduce alcohol (2)
* Increase intelligence (3)
* Increase exercise (4)
* Increase coffee consumption (5)
* Reduce BMI (6)
* Reduce diabetes (7)
* Reduce heart disease (8)
* Reduce smoking (9)
* Increase education (10)
* Reduce insomnia (11)
* Reduce loneliness (12)
* Reduce neuroticism (13)
* Increase wellbeing (14)
* Reduce depression (15)
* Reduce worry (16)

Q74 Select intervention(s) to **most reduce smoking,** whilst most improving the overall physical and mental health of the network.

* Increase eveningness (1)
* Reduce alcohol (2)
* Increase intelligence (3)
* Increase exercise (4)
* Increase coffee consumption (5)
* Increase socialisation (6)
* Reduce BMI (7)
* Reduce diabetes (8)
* Reduce heart disease (9)
* Increase education (10)
* Reduce insomnia (11)
* Reduce loneliness (12)
* Reduce neuroticism (13)
* Increase wellbeing (14)
* Reduce depression (15)
* Reduce worry (16)

Q75 Select intervention(s) to **most reduce heart disease,** whilst most improving the overall physical and mental health of the network.

* Increase eveningness (1)
* Reduce alcohol (2)
* Increase intelligence (3)
* Increase exercise (4)
* Increase coffee consumption (5)
* Increase socialisation (6)
* Reduce BMI (7)
* Reduce diabetes (8)
* Reduce smoking (9)
* Increase education (10)
* Reduce insomnia (11)
* Reduce loneliness (12)
* Reduce neuroticism (13)
* Increase wellbeing (14)
* Reduce depression (15)
* Reduce worry (16)

End of Block: Area of competency 7

# Supplementary table 3. Intended Learning Outcomes

*Note*: Numbers in left margin correspond to areas of competency:

1. Ability to read information about nodes and edges in the network visualisation
2. Understanding of direct effects: Infer the direct effects of interventions which increase the prevalence of a trait
3. Understanding of network properties: Ability to make general inferences about the network
4. Understanding of interactions: Critically analyse interaction effects between multiple interventions which increase the prevalence of different traits
5. Ability to negate effects: Infer the direct effects of interventions which decrease the prevalence of a trait
6. Understanding of indirect effects: Infer the indirect effects of interventions which increase the prevalence of a trait
7. Working understanding of complex network effects: Ability to design solutions to public health problems involving multiple interventions which have a mix of direct and indirect effects, which both increase and decrease traits

|  |  |  |
| --- | --- | --- |
|  | **Intended Learning Outcomes**  *at this stage learners should have learned…* | **Assessable competencies**  *at this stage learners should be able to…* |
| 1 | Nodes represent traits | a.       Identify which traits are present in the network |
| Trait names are represented with labels on nodes | b.       Identify whether two traits share a direct relationship |
| Edge colour represents valence | bii. Identify the colouring of arrows in visualisation |
|  |  |
| Edges represent relationships | c.       Describe a direct relationship between two traits in terms of strength, directionality, valance (increase/decrease) and whether it is bi-directional |
| Edge width denotes effect size |  |
| Nodes can have both incoming and outgoing effects, and the directionality of edges is represented with arrowheads |  |
| Effects propagate to connected nodes |  |
| The prevalence of traits is represented in the network, and is represented by the area of a node |  |
| 2 | Increasing the prevalence of a trait results in immediate effects on traits with which it shares direct relationships | a.       Hypothesise how an intervention to increase one trait would affect another trait which shares a direct relationship |
| Interventions often have multiple effects | b.       Select (*def: from a list of choices*) the correct trait to intervene on in order to directly increase/reduce a given trait |
| The immediate effects of an intervention which increases a trait (node) are equal to its outgoing effects (edges) | c.       Select the optimal trait to intervene on in order to most increase/reduce a given trait directly |
| Positive relationships (edges / effects with positive beta weight values) increase the prevalence of the target node |  |
| Negative relationships reduce the prevalence of the target node |  |
| 3 | The network contains traits which are both good and bad for physical and mental health | a.       Infer whether the consequences of an intervention would be generally beneficial or detrimental to the mental and physical health of the population |
| The general physical and mental health of the population is represented by the sum prevalence of each trait in the network | b.       Infer whether the overall effects of interventions in the network on mental and physical health are generally good or bad |
| The overall mental and physical health of the network can be changed through interventions | c.       Identify the most central traits in the network (traits with most and largest effects) |
| Some nodes have a greater number or magnitude of incoming and outgoing effects | d.       Identify that the number of outgoing effects is equal to the number of incoming effects |
| A node’s influence on other traits in the network (‘centrality’) is a function of both the number and magnitude of outgoing effects |  |
| Some nodes are more influential (‘central’) than others |  |
| The number of outgoing effects is equal to the number of incoming effects |  |
|  |  |
| 4 | Interventions can have surprising and unintended side-effects | a.       Hypothesise the direct effects of multiple concurrent interventions |
| Interventions can have a mix of both good and bad side-effects on the general mental and physical health in the network | b.       Select a combination of multiple traits to intervene on concurrently to best solve a problem |
| Different interventions can affect the same trait in different ways |  |
| Multiple interventions can be enacted concurrently, and their effects can interact with eachother |  |
| When intervention effects interact their overall effect is calculated by adding their effects together |  |
| 5 | Interventions can reduce the prevalence of traits | a.       Correctly identify that an intervention to reduce a trait results in the opposite effects than interventions to increase traits (i.e., effects which increase other traits instead decrease them) |
| When an intervention reduces a trait’s prevalence the outgoing effects are negated in valence (i.e., a reduction effect becomes an increase and vice-versa) | b.       Hypothesise how an intervention to decrease one trait would affect another trait which shares a direct relationship |
| To calculate the direct effects of reducing the prevalence of a trait, one has to negate the valence of outgoing effects |  |
| 6 | A trait can have an indirect effect on a target trait by first affecting another trait (a mediator) which is connected to the target and causes a consequential effect on it (e.g., BMI Diabetes Heart disease CHD) | a.       Identify whether distant traits share an indirect relationship through a pathway |
| Indirect effects can involve one mediator (1st order mediation: as above) or many mediators (e.g., 2nd order mediation: Education BMI Diabetes Heart) | b.       Hypothesise how an intervention to increase one trait would cause knock-on consequences on a distant trait which it shares an indirect pathway relationship with |
| Effects propagate through related nodes in the network | c.       Identify that the direct effects of interventions are often greater in magnitude than the indirect effects |
| The indirect effects of interventions can be thought of as a series of steps in a pathway | d.       Select a trait to intervene on to achieve an effect on a trait with which it shares a first-order indirect relationship |
| The indirect effect between two traits is calculated as the sum of each step in the pathway of effects | e.       Calculate the total effect of an intervention as the sum of the direct and indirect effects |
| The total effect of one trait on another is equal to the direct effect plus the indirect effect | f.        Identify that more complex indirect effects (i.e., second/third order mediation) continue propagating through the network until they reach an end node |
| The magnitude of the outgoing effects for a trait are usually greater when it is intervened on directly rather than indirectly (i.e., as a step in a pathway) | g.       Select a trait to intervene on to achieve an effect on a trait with which it shares a second/third-order indirect relationship |
| 7 | Steps in effect pathways can have a mix of valences (i.e., effects which both increase and decrease traits) | a.       Hypothesise how an intervention to increase/decrease one trait would cause knock-on consequences on a distant trait which it shares a complex indirect pathway with a mixture of increasing and decreasing effects |
| Indirect effect pathways can be complex and their effects difficult to predict especially when pathways have many steps which are mixed in valence | b.       Design the optimal intervention (*def: free-choice combination of up to 3 traits*) to achieve an objective whilst best improving the physical and mental health of the population |
| In complex indirect effect pathways, when a trait is reduced (in prevalence as a step in a pathway) the next steps are negated in valence |  |
| Combining multiple interventions makes it more difficult to predict and control side-effects |  |