4.14 Natural experiments in a hazard context

Authors

Hyun M. Kim, School of Health Sciences, University of Canterbury - Te Whare Wānanga o Waitaha, Christchurch, New Zealand.

Alex G. Stewart, College of Life and Environmental Science, University of Exeter, Exeter, United Kingdom.

Philip J. Schluter, School of Health Sciences, University of Canterbury - Te Whare Wānanga o Waitaha, Christchurch, New Zealand.

4.14.1 Learning objectives

To understand the potential utility of natural experiments in health emergency and disaster risk management (Health EDRM), including:

1. Process of conducting a natural experiment in a disaster context.
2. Framework for, and outcomes of, natural experiments.
3. Important strengths and limitations of natural experiments.

4.14.2 Introduction

Health researchers are often interested in understanding the effects of certain conditions on health risk or disease outcomes. Typically, constructed and controlled experiments are the cornerstone of studying such causal relationships between exposures and outcomes. An exposure can be any type of condition that is associated with an outcome of interest. For example, the efficacy of influenza vaccine (exposure) can be analysed in relation to the frequency of influenza illness (outcome). In the context of traditionally designed medical experiments, such as randomized trials, exposures are manipulated and are often termed 'treatment'. By contrast, natural experiments are characterized by exposures that are unexpected and cannot be controlled nor manipulated. This exposure may still be referred to as 'treatment' since it essentially performs the same role as the treatment in a randomized trial. Chapter 4.1 explains how to design, conduct and interpret randomized trials in the context of Health EDRM. This chapter discusses natural experiments, an alternative method for studying causal associations. The key components of a causal framework for natural experiments are briefly described in table 4.14.1.

Table 4.14.1 Main components of natural experiments

Component	Description
Exposure/ treatment	'Exposure' broadly refers to any factors (biological, behavioural, lifestyle, environmental) that are being studied in relation to an outcome of interest. 'Treatment' is a technical term that embraces a variety of exposures that differ across experimental groups. In natural experiments, exposures are often disasters caused by natural hazards or anthropogenic (human-instigated) hazards that are typically outside the researchers' control (for example, earthquake, weather shocks and conflicts), and may still be referred to as 'treatment'.
Outcome of interest	'Outcome' is a generic term for the various results that are being investigated in relation to a particular exposure or treatment. In epidemiological and health research, outcomes usually refer to incidences of diseases and health risks. In natural experiments, the hypothesized or observed effects of natural and anthropogenic hazards can be studied as outcome variables. For example, cancer (outcome) can be studied among the population exposed to radiation as a result of breach in a nuclear power plant.
Treatment group	The treatment group describes those people who are assigned to receiving the experimental treatment. In natural experiments, treatment groups are exposed to natural or anthropogenic hazards not by design or deliberate random assignment, but by chance. The treatment unit may be individuals or clusters of people according to affected geographical or jurisdictional borders, regional policies or household units.
Control group	The control or comparison group serves as a reference group in an experiment. In randomized trials, people in the control group might be given the existing best treatment or a placebo, instead of the treatment being tested. In natural experiments, the control or comparison group may be less exposed (or unexposed) to a hazard than the exposed or treatment group since there may be a range of exposure types or concentrations.
Instrumental variables	Instrumental variables are a proxy measure for the independent variable of interest. In the natural experiment context, instrumental variables are often used when the exposure or treatment is difficult to directly measure or quantify (see Case Study 4.14.3). Alternatively, instrumental variables may be related to other variables that could independently influence the outcome (for example, unobserved factors or factors that are not directly included in the model), but may still influence the outcome (see below for an example using *(1)*).
Confounding factors	The exposure-outcome relationship can be influenced by factors that are associated with both the exposure and the outcome. For example, when studying the efficacy of influenza vaccine on reducing the occurrences of flu related illnesses, chronic medical conditions in patients can be a potential confounder (example adapted from *(2)*). Patients with chronic medical conditions or compromised immune system are more likely to be vaccinated (association with the exposure) and more likely to contract influenza viruses (association with the outcome). However, the chronic conditions are unlikely to be directly on the causal path (that is, influenza vaccination can cause chronic illnesses, which in turn, can cause influenza illnesses), and not being directly on the causal pathway is an important condition for a confounding variable *(3)*. In observational studies, any presence and effects of confounding factors need to be taken into account when analysing causal relationships.

A traditional randomized trial design exhibits at least the following three characteristics: 1) random assignment of people into the exposure/treatment and control/comparison groups; 2) researchers' having and exercising control over exposure/treatment assignments; and 3) comparison of outcomes between exposed and control groups. The mechanism of randomly assigning people into exposure/treatment and control groups is of fundamental importance, as it implies that, on average, people across these groups are similar to each other in both known and unknown pre-exposure characteristics *(3)*. This pre-exposure equivalence ensures that any confounding effects from factors that are related to both the exposure and the outcome of interest are balanced across the groups and removes the need for including confounding variables in models and explicitly analysing their effects. Despite this appealing feature, the traditional experimental design is not always a feasible or a practical option. For instance, it would be impossible to control and unethical to simulate a disaster.

Disasters and hazards of various kinds are occurring more frequently and in greater severity. With the world's rapidly expanding and dispersing population together with the impacts of global environmental change, these disasters have greater potential to significantly impact our planet's environmental integrity and its people's health and wellbeing *(4)*. Such occurrences alter the way people live and respond in the affected areas on a scale that would often be logistically or ethically implausible to implement a study using traditional experimental designs *(4)*. Yet, robust evidence-based and informed strategies are needed to serve the affected populous and their environments, together with those experiencing similar events elsewhere or in the future. Natural experiments are, by design, adaptations of conventional approaches or novel methods in providing this evidence-base for Health EDRM. Concordantly, there has been a dramatic increase in the implementation and publication of studies purporting to use natural experiment designs, although their internal validity varies greatly *(5)*.

The randomized trial design is often posited as the minimal standard in considering causation of an effect. However, conventional random assignment, which is the hallmark of randomized trials may be impossible in the disaster context. Nonetheless, it is still possible to have populations that can be demarcated into exposure (treatment) and control groups via a mechanism that is (nearly) as good as random assignment *(6)*. When there is a well-defined exposure that can be contained within a sub-population, and this sub-population is exposed as if in a random assignment, then the natural (or quasi-natural) experimental framework can be used as an alternative to the randomized trial design to infer cause and effect. This chapter follows the convention of Dunning *(5)* and refers to the assignment mechanism that results from an accidental exposure of certain groups of people and which is as good as random as being an 'as if' random assignment. An exposure to a natural or human-instigated (anthropogenic) hazard is an example where natural experiments have been used to understand their impacts on a subject population. This chapter looks at how natural experiments can be used in a hazard/disaster context and the strengths and limitations associated with the framework.

4.14.3 Natural experimental framework

The natural experimental framework has embedded in its structure many of the elements that characterize randomized trials. These include the exposure, control and outcomes that are outlined in table 4.14.1. When a disaster occurs, such as an earthquake, a well-defined exposure can then be defined which is known to affect all people within a particular perimeter. These people can be considered as comprising the exposed group. Those outside this perimeter remain unaffected and can be categorized as the unexposed, control or comparison group. In some cases, the level of exposure may vary across people and those who are less directly affected may also need to be considered in the analysis.

The focus of using and reporting a natural experiment should be on establishing validity and making a plausible argument for a treatment assignment that is as good as random, or for the difference in exposure of two or more groups. The onus is on the researcher to make a compelling argument for the credibility of 'as if' random assignment by providing both quantitative and qualitative evidence. In a natural experiment with a persuasive 'as if' random assignment argument, the groups are assumed to be similar in all pre-exposure characteristics including any confounding factors, as in the case for true randomization. However, natural experiments are in fact observational studies as the manipulation of 'treatment' cannot be controlled by the researcher as in a true experiment. It is important to distinguish natural experiments from other observational studies, such as quasi-experiments and matching designs (Chapter 4.5), where assignment is neither random nor 'as if' random and hence confounding (both observed and unobserved) becomes an issue to the validity of causal inference *(5)*. In such cases, the effects from confounding factors may need to be explicitly taken into account by adding the confounding variables to the outcome-exposure model and analysing their effects on the association.

In a natural experiment with convincing 'as if' randomization, the data analysis is often simple and interpretable. It usually involves comparing the estimated outcome means between differently exposed groups. For instance, when analysing the level of anxiety after an earthquake, the average effect can be estimated by the average level of anxiety (measured using some form of testing) for all those who experienced the earthquake (by some definition) compared to those who were unexposed to the earthquake. In some natural experiments, exposure/treatment assignment happens at the cluster level (for example, policy implementation in cities, jurisdictional borders or natural boundaries) related to the exposure under consideration. The simplest approach to analyse the average causal effect is to use the average cluster means (that is analyse at the level of random assignment). For example, when analysing the efficacy of a district-wide policy roll-out which affects everyone within the district but not those outside the district boundaries, the average effect is estimated by comparing the average outcomes across different districts rather than across individuals. Sometimes, this is not possible and more sophisticated approaches are needed (see *(5)*).

Three key elements are considered in a typical process for implementing a natural experiment: study design, statistical analysis and validation.

4.14.4 Study design

Exposure-outcome causal model is defined and causal parameters of interest are determined. The 'as if' random assignment argument is also validated using suitable quantitative and qualitative methods. At this point, research hypotheses around the effects of exposures can be considered and formalized.

4.14.5 Statistical analysis

When assumptions around 'as if' random assignment and other model assumptions related to analysing experiments are met, the Neyman–Rubin potential outcomes model is often applied (*7*). One important model assumption is the 'non-interference' assumption: the independence of the effects of exposures across participants, that is, the effects of exposure on one individual do not influence the effects of exposures on other participants and vice versa. Another key assumption is the 'excludability': the effects of exposure on the outcome depend only on the exposure itself and not on other features of the experiment. In a strong natural experimental design, the average exposure/treatment effect is estimated by the difference between average values of observed outcomes for all participants in the exposed groups compared to those in the control/comparison group.

4.14.6 Validation

Quantitative methods are available to test the assumptions about similarities in pre-exposure characteristics between the participant groups. Hence, before the exposure, numbers of participants in each sex, demographic, and other socioeconomic backgrounds are balanced across the exposed and comparison groups almost as if they were randomly assigned to these groups.

Qualitative knowledge about context and process is equally crucial for establishing internal validity in treatment assignment, the integrity of exposure-outcome causal model and the assessment of model assumptions such as non-interference and excludability. Qualitative knowledge is also essential for reporting and assessing external validity such as in replicability and generalisability of results.

4.14.7 Natural experiment designs and their applications

Disasters due to natural hazards often strike with little or no warning and can impact on any population regardless of their attributes, which render disasters persuasive circumstances for implementing a natural experimental design. Perhaps not surprisingly, the natural experimental framework has increasingly been used in broad natural/anthropogenic hazard contexts. For example, the framework has been extended to analyse the impact of arguably one of the most critical natural and anthropogenic hazards that we face today: climate change. Case Study 4.14.1 illustrates a study where children's wellbeing outcomes (measured by undernourishment, labour force participation, and adequacy of medical attention) were analysed in the aftermath of devastating Hurricane Mitch in Central America (October-November 1998).

4.14

Case Study 4.14.1
Children's vulnerability to weather shocks: A natural experiment *(8)*

Agricultural societies are often more vulnerable to weather shocks such as severe storms and hurricanes. Hurricane Mitch hit Nicaragua in the last week of October of 1998, and was one of the most destructive storms ever to strike Central America. It left behind more than 50 inches (1.27 metres) of rain and more than 20% of the population was in need of new housing. But, not all municipalities within Nicaragua were directly affected. Fortuitously, a household-level survey had been initiated before the hurricane, the Living Standards Measurement Study (LSMS), which collected data in 1998, 1999 and 2001. Exploiting the LSMS, wellbeing outcomes of Nicaraguan children residing in areas affected by Hurricane Mitch were compared to their unaffected counterparts using a 'double difference' analysis.

The assumption about 'as if' random assignment was made based on the unpredictability of the location of the impact, and that any region was as likely to be on the path of the hurricane as any other regions nearby. The children from households in the municipalities severely affected by the hurricane were analysed as the exposed group. The children from households located outside these areas were used as the comparison group. Validity checks were performed using both quantitative and qualitative methods. The characteristics between the exposed and less exposed households were analysed to validate the 'as if' random assignment argument. Rural areas were more directly hit by the hurricane and the differences in median income and parental educational attainment were detected between the exposed and less exposed groups. These differences were controlled once the treatment effect was conditioned on location. The households were used as the instrument for assigning children into exposure groups. This implies that, after conditioning on location, the outcome of interest (demand for education and health services) was only influenced by whether the households were directly exposed to Hurricane Mitch or not, and not by other underlying household characteristics or other unobserved factors.

Qualitative checks were also performed to analyse the disruption in the supply of school and health services due to the hurricane, as this was considered a potential confounding factor for the demand for those services. The study found that children living in the regions affected by Hurricane Mitch were 30% less likely to be taken for medical consultation when sick, experienced 8.7% increase in the probability of being undernourished, and had 8.5% increase in labour force participation. Although the randomization unit was at the household level, the analyses were performed at the individual child level. The correlation between children within the same household needs to be taken into account when computing variability estimates. However, the extensive validity checks performed in this study to assess the 'as if' random assignment argument were exemplary.

Novel ways of adapting natural experimental designs are continuously being devised. One illustration is a study looking at the application of natural experiment to evaluate cyber security policies *(9)*. Digital hacking is

a relatively new type of man-made security hazard that could place huge cost and burden on people and systems at a global level. Much investment has been made by many countries and organizations on building capacity to deal with any potential breach in cyber security and yet, testing such systems is challenging. Natural experiments are proposed as an alternative to costly and, in some cases, unethical application of traditional experimental design in evaluating the integrity of such programmes.

4.14.8 Regression-discontinuity design

Regression-discontinuity designs are natural experiments where treatment assignment depends on a certain threshold value of a variable (Chapter 4.5). For example, patients may receive a new type of drug depending on their measure of blood pressure being above a certain cut-off value. Around the levels very close to this cut-off, the patient characteristics may not differ greatly even though they are assigned into two distinct groups: those who receive the new drug and those who do not. It can be graphically characterized by a jump or break in the trend for the probability of receiving a treatment versus control around this value of the variable. The 'as if' random assignment argument is only plausible for cases around the near neighbourhood of this threshold as observations farther apart are likely to differ more systematically. In the above example, patients with blood pressure much higher than the cut-off value are likely to have very different lifestyle characteristics than those with values much lower than the cut-off used. So any observed differences between the outcomes being studied may be due to these lifestyle differences rather than the new drug. Case Study 4.14.2 is an application of a regression-discontinuity design for studying the changes in people's lifestyle choices and provision of healthcare services as a result of the 2011 Great East Japan Earthquake (Chapter 1.3) *(10, 11)*.

Case Study 4.14.2
Residential relocation and obesity after a disaster: A natural experiment from the 2011 Great East Japan Earthquake and tsunami (adapted from (11))

Residents in a neighbourhood typically share common demographic characteristics or lifestyle patterns. However, when the east coast of Japan was hit by a massive earthquake and tsunami in 2011, a large-scale exodus ensued that could not have been foreseen nor planned. Approximately 345 000 people were displaced from their homes, disrupting their normal way of life and possibly their long-term wellbeing. This disaster was used as the 'as if' random assignment mechanism where the outcomes of survivors before and after the earthquake were compared. Coincidentally, a nation-wide cohort study of ageing population, the Japan Gerontological Evaluation Study, had been established seven months before the earthquake, allowing the researchers to investigate the impact of disaster in comparison to the extensive pre-disaster information available on the cohort.

For example, the cohort was followed up about 2.5 years after the disaster to study the impact of relocation on 3594 participating survivors' weight gain measured using the Body Mass Index (BMI). The change in the

distance to the nearest food outlets, bars, supermarkets was used as an explanatory variable in a fixed effects multinomial logistic regression model. Various covariates such as age, socioeconomic status and mental health and behaviours were also added in the analysis. Adjustments for confounding variables are necessary if systematic differences between the survivors pre- and post-disaster are to be assumed. The study found that moving 1km closer to supermarkets, bars or fast food outlets increased the odds of BMI change from normal to the obese range by 1.46 (95% confidence interval (CI): 1.15 to 1.86), 1.43 (95% CI: 1.11 to 1.86), and 1.44 (95% CI: 1.12 to 1.86), respectively. Such findings suggest that the impact of a disaster on survivors' lifestyle choices is of pervasive nature, and could have long-term health and wellbeing implications.

The discontinuity in Case Study 4.14.2 is at the point of the disaster, when changes can occur and differentiate people's post-event characteristics from those of before. Around the time of event, the probability of being exposed to certain risks can be higher for people within the vicinity of the disaster compared to those further away. Some changes, such as the residence displacement, will likely be irrevocable, and the consequences of those can be analysed as illustrated in Case Study 4.14.2.

In Chapter 2.4, Case Study 2.4.1 described an example in which the impact of moving toward a more integrated health system on emergency room attendance and acute admission rates was analysed for the population affected by the 2011 Christchurch, New Zealand earthquake *(12)*. Figure 2.4.1 in Chapter 2.4 shows visible breaks in the trends for emergency room attendance and admission rates before and after the earthquake.

4.14.9 Instrumental variables design

Instrumental variables are proxy measures for the actual variable of interest that may be difficult to measure or could lead to biased estimation. In instrumental variables design, people are assigned at random (or 'as if' random) to this proxy for the variable of interest. For example, Angrist *(1)* sought to measure the long-term labour market consequences of those veterans who served in the military during the Vietnam era compared to their nonveteran counterparts. Here, military draft eligibility was used instead of actual military service in a natural experiment design which produced robust unbiased estimates. Using the military draft eligibility as an instrumental variable ensured that all those who were subject to randomization were analysed rather than those who complied with the assigned treatment (that is, completed military service). Furthermore, those who volunteered to serve or those who did not pass the health tests after being randomly selected for draft eligibility would have had different characteristics to those who did not serve in the military. So, it was important to use the draft eligibility, which was closely associated with actually serving in the military, but also would not otherwise influence an individual's lifetime earnings.

Case Study 4.14.3 *(13–14)* explores prevalence of iodine deficiency disorders that are endemic to areas characterized by subducting plates in the Himalayan region. Iodine deficiency is a disaster that is not sudden, but is easily preventable. It is a devastating issue in many communities due to

its link with high levels of infertility and miscarriages, cretinism and lowered cognition, as well as the usually harmless but visible goitre. The research described in the case study focuses on the Baltistan region, northeast Pakistan, before any long-term iodization programmes, where clear regional differences in prevalence of goitre were found north and south of the Main Karakoram Thrust, where Asia and India meet geologically, giving a natural experiment. This experiment is characterized by exposure ('north-south goitre prevalence') that is unexpected and cannot be controlled nor manipulated. It can be argued that selection of individuals was "controlled" precisely on the basis of the north-south goitre prevalence, leading to the outcome of the incidence of iodine deficiency. The geological separation was used as an instrumental variable in categorising two communities by their environmental differences, which were otherwise difficult to quantify (for example, geological and geochemical differences).

Case Study 4.14.3
Differences in endemic goitre prevalence in the Karakoram mountains, north Pakistan: a natural experiment suggesting an unrecognized cause (adapted from *(13)*)

Environmental iodine deficiency, of which endemic goitre is one manifestation, causes several disorders, none of which were seen as related to goitre by the local community in Baltistan, northern Pakistan in the 1980s. However, the community noted that more people living in the north of the region suffered from goitre than did those living in the south. Furthermore, goitre was accepted as normal, not triggering clinic visits. Careful qualitative investigation of the communities on both sides of the rivers did not show any north-south differences in ethnicity, diet, farming practices or other obvious causes of the difference. Residence village was used as the 'as if' random assignment mechanism.

New patients attending a clinic fell naturally into four groups: northerners with goitre, northerners without goitre, southerners with goitre, southerners without goitre. There was a significant difference in prevalence due to age-sex and, independently, to residence north or south of the Main Karakoram Thrust. This plate tectonic boundary divides the region into two clearly distinct geologies, and increased the prevalence in the north by 15-18%. A literature search revealed two other studies by another team more than 100 miles to the west, straddling the Thrust. Findings were similar: villagers on the northern plate had consistently more goitre. The geology was the explanatory variable, and indicates that the distribution of iodine deficiency disorders in this and other mountain ranges are likely related to plate tectonics in addition to iodine deficiency.

The study shows most of the strengths in Table 4.14.2. This robust observation allows prediction of the distribution of iodine deficiency disorders which can be tested by further observational studies, with a stronger hypothesis than many of the standard explanations for the occurrence of iodine deficiency disorders, such as leaching of soil iodine by rain or removal by glaciation.

Table 4.14.2 Strengths and limitations associated with natural experiments for Health EDRM

Strengths	Limitations
No ethical constraints about exposure.	No control over baseline differences in the exposed and less or unexposed groups.
Can infer cause-effect when 'as if' randomization can be validated.	There is no random assignment in the traditional sense, which may restrict causative assertions if 'as if' randomization cannot be established.
Obviates confounding typical in an observational study.	May be difficult to contain the treatment and control groups within certain temporal and spatial perimeters.
Quantitative analysis can be simple and transparent.	May be difficult to isolate an effect of an exposure.
Statistical results often easy to interpret.	Exposure/treatment may not be of research relevance or interest.
Can be less costly than the randomized trials or quasi-experiments if data already available.	Internal and external validity may be difficult to analyse.
Can be tailored to the hazard or disaster.	
Possible to analyse the effect of a slow onset hazard.	
Possible to plan a prospective study.	

Countries and jurisdictional borders can form natural clusters. In some cases, they can be used as instrumental variables for studying various social, political, environmental and health related differences across groups. Historical borders and policy differences across countries are usually outside the control of the researchers (that is, exogenous to the model). The administrative and structural differences also mean that the countries are 'as if' assigned to different types of treatments. When applying instrumental variables, it is important to check that the outcome of interest is influenced mainly through the association between the instrument used and the explanatory variable being studied, and not through other factors unexplained by the model. For example, in Case Study 4.14.3, demographic characteristics between two communities were analysed to ensure that the instrument used, which was related to the geology of the region, was what explained the observed difference in prevalence of goitre, and not the demographics.

In another example, the extent of food insecurity across 21 countries was analysed in relation to the economic hardship, measured using the unemployment rate and decrease in wages, experienced during the 2004-2012 European recessions *(15)*. The country-level analyses revealed that both measures of economic hardship were associated with an increased sense of food insecurity. Also taking advantage of jurisdictional and policy differences, the association was further analysed using the level of social protection in each country. The risks of food insecurity associated with economic hardship were mitigated in countries that spent more on provision of social protection.

Similar designs have also been applied in studies looking at the effects of environmental policies implemented at the prefecture- or city-level of governance. Environmental regulations on sulphur dioxide emission and

acid rain were put in place across different provinces in China in order to reduce air pollution *(16)*. The resulting changes in the volume of industrial activities in the regulated cities were compared to those of unregulated cities. Similarly, gains in energy efficiency following the roll out of 'Smart City' policies in China (aimed at integrating government services and achieving low carbon emitting and ecologically sound urbanization plans) were analysed and compared across the 'Smart Cities' and control cities *(17)*.

Other examples where country-level policy differences have been used to analyse human-instigated hazards can be found in studies of health risk control policies. The impact of tobacco control policy on cardiovascular morbidity and mortality in Russia was analysed in relation to other countries without such control *(18)*. Similarly, the implementation of trans fatty acid control policy in Austria was used as the setting for a natural experiment where the cardiovascular and coronary heart disease mortality was compared between the population under the regulation and the international control population from countries without the regulation *(19)*.

4.14.10 Conclusions

Natural experiments provide researchers with opportunities to investigate some topics of relevance to Health EDRM that are not amenable to designs, such as randomized trials. They have important strengths and limitations for hazard and disaster epidemiology, which are listed in Table 4.14.2.

4.14.11 Key messages

- **In natural or human-instigated hazard contexts, implementing the traditional experimental design to study cause-effect relationship can be unfeasible or unethical.**
- **When people are assigned into exposure/treatment and control groups by chance, but in a way that resembles true randomization, natural experiments can be used to infer relationships between exposures and outcomes, just as in a traditional experiment.**
- **The credibility and validity of natural experiments depend on the persuasiveness of the 'as if' random assignment argument. The randomization ensures that the exposed and control groups are similar in their pre-exposure characteristics and hence mitigates the effects of observed and unobserved confounders.**
- **Quantitative analyses of pre-exposure characteristics and qualitative evidence around context and processes are useful for establishing the credibility of natural experiment design.**
- **If the assumption of random, or 'as if' random, assignment is persuasive, then the estimation of causal (or treatment) effect is as simple as taking the difference between the means of outcome from the treatment and control groups.**

4.14.12 Further reading

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