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Effectiveness of different types of motorcycle helmets and effects of their improper use on head injuries

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Background Differences among three helmet types and the ineffectiveness of improper helmet use in preventing head injuries are speculated about but are seldom explored with evidence. A case–control study was conducted to examine how different helmet types and improper helmet use affected protection against head injuries among motorcyclists in Taiwan.

Methods Case motorcyclists comprised 435 persons who sought emergency care due to head injuries at a medical centre in west-central Taiwan over an 8-month period and 23 motorcyclists who died from head injuries at the scene of the crash; 458 motorcyclists who had non-head injuries were used as the control group, and their crashes occurred within 1 hour earlier or later than the corresponding cases. Information on helmet type was validated by interviewing motorcyclists who were refuelling at petrol stations.

Results A conditional logistic regression analysis showed that compared with helmeted motorcyclists, non-helmeted motorcyclists were more than four times as likely to have head injuries [odds ratio (OR) 4.54; 95% confidence interval (CI) 1.25–16.5] and ten times as likely to have brain injuries (OR 10.4; 95% CI 1.82–59.2). Compared with motorcyclists wearing full-face helmets, those wearing half-coverage helmets were more than twice as likely to have head injuries (OR 2.57; 95% CI 1.50–4.40) and brain injuries (OR 2.10; 95% CI 1.01–4.38). Compared with motorcyclists with firmly fastened helmets, those with loosely fastened helmets increased their risk of head injury (OR 1.94; 95% CI 1.33–2.82) and were more than twice as likely to have brain injuries (OR 2.50; 95% CI 1.47–4.25).

Conclusions Of the three helmet types, half-coverage helmets provided motorcyclists the least protection from head injuries. Furthermore, wearing a loosely fastened helmet may compromise any potential protection.

Keywords Head injury, helmet, motorcycle, case–control study, crash severity, epidemiology

Introduction

Head injuries lead to high mortality rates and incur enormous economic costs;[1,2] they are the most serious public health problem for motorcycle riders, particularly in developing countries.[3,4] In the USA, motorcycles are generally used for recreation and comprise ~2% of registered motor vehicles.[5] In contrast, in many Asian countries, motorcycles are one of the most important means of transportation, and riders have especially high rates of injury.[6] For example, motorcycle crashes account for 81% of head injuries in Vietnam[7] and >50% of head injuries in Malaysia[8] and Taiwan.[9]

Empirical evidence strongly supports the conclusion that wearing a helmet protects motorcycle riders from the high risk of head injuries and death.[10–13] This evidence has facilitated legislation requiring mandatory motorcycle helmet use in many states in the USA and in many other countries.[14–19] Wearing a helmet effectively reduces head injuries among motorcyclists; even so, a substantial proportion of motorcycle riders who wear helmets still sustain head injuries in crashes.[20,21] Three helmet types, full-face, open-face and half-coverage, are commonly used by motorcycle riders; their effectiveness in preventing head injuries may differ and some types might even be inadequate. It is not uncommon to observe a helmet becoming detached in a motorcycle crash;[21,22] for example, nearly one-fourth of helmets came off during crashes in Thailand and 5% in Los Angeles, CA, USA.[23] Moreover, head injuries seem to occur more frequently and are more severe for riders who wear a non-standard helmet than those who wear a standard helmet.[24] The use of borrowed and poorly fitting helmets is widely reported in many developing countries and more than one-third of riders exhibit improper helmet use, such as wearing it on the back of the head and having a loose chin strap.[25,26]

To our knowledge, potential differences in the effectiveness of various helmet types have not been adequately examined, and no study has explored the effects of improper use of helmets on head injuries among motorcycle riders. To address these issues, a case–control study was conducted to examine the effectiveness of different helmet types and improper helmet use in protecting against head injuries among motorcyclists.

Materials and Methods

Study subjects

China Medical University Hospital is a 2200-bed, level-I trauma medical centre and can manage ~50% of emergency patients in the city of Taichung, west-central Taiwan. During an 8-month period from 1 January to 31 August 2008, patients aged ⩾15 years who lived in Taichung and visited the emergency room at China Medical University Hospital due to motorcycle injuries were eligible for this study. Cases were selected from among motorcyclists who sustained head injuries with the presence of at least one of the following conditions: lacerations, abrasions and bruises to the scalp, forehead and ears; fracture of the skull and face; and brain injury, since a helmet might reasonably be expected to protect these areas of the head. Brain injury was defined as a diagnosis of concussion, cerebral contusions and lacerations, intracranial haemorrhage, loss of consciousness or post-traumatic amnesia. Furthermore, according to medical examiner records, 23 motorcyclists who were citizens of Taichung died from brain injuries at the crash scene during the study period. Riders who were not operating a motorcycle—i.e. those who were riding a minibike, a bicycle or a tricycle or wore a safety helmet for construction or were involved in a crash outside the city of Taichung—were excluded from the study.

For each case, a control was matched to the crash time, selected by incidence density sampling from injured motorcyclists who sought care at the same emergency room due to a crash resulting in injury to the body but not the head. The crash time of the control patient occurred within 1 h before or after that of the case. Matching was presumed to exclude confounding effects from environmental factors such as weather, road conditions and traffic volume. A potential control was excluded if she/he had a history of a previous head injury.

In total, 458 case–control pairs participated in the study. With the significance level set to 0.05 and the power to 0.80, a sample size of 388 pairs was required if the prevalence of wearing half-coverage helmets was 0.60 in case motorcyclists and 0.50 in control motorcyclists,[27] and 356 pairs were required if the prevalence of improper helmet use (e.g. loosely fastened) was 0.40 and 0.3 in case and control motorcyclists,[28] respectively. This research was approved by the Institutional Review Board of Taipei Medical University, and informed consent was obtained from participants or the family of deceased riders.

Exposure measurement

Exposure data were collected from medical records and personal interviews. Information on demographics such as age, gender, height, weight and educational level was extracted from medical records. In addition, a research nurse in the emergency room interviewed participants using a standardized questionnaire. For those who were fatally injured or unable to communicate during their stay in the emergency room, their companions or paramedics were interviewed.

During the interview, information was collected about helmet-related characteristics (see below), motorcycle licensure, safety-related traffic violations in the past year, riding speed, alcohol consumption at the time of the crash, motorcycle engine volume ($\leqslant$50, 70–110 and $\geqslant$125 cc), collision type (rear-end, head-on or single-vehicle crash) and collision object (moving motorcycle, moving car, other moving object, stationary object and no object hit).

Helmet-related characteristics

The study had two hypotheses: full-face, open-face and half-coverage helmets perform differently in preventing head injuries; and improper helmet use reduces its effectiveness in preventing head injuries. Helmet-related characteristics consisted of helmet use (helmeted or non-helmeted), helmet type, helmet ownership (driver or other), helmet fit (good or poor fit) and helmet cost (<300, 300–600 and >NT$600) (the exchange rate at the time of the study was ~US$1.00 = NT$32.00), the manner of wearing the helmet (covering the entire head, worn on the back of the head or worn in reverse), fastening status (firmly or loosely fastened), helmet visor (pulled down, not pulled down or without a visor) and helmet fixation during the crash (fixed on the head, displaced but still on the head or had come off). Improper helmet use that might impair the maximum protection in a crash was ascertained in terms of a borrowed helmet, a poorly fitting helmet, a poor-quality helmet (indicated by helmet cost <NT$300), an incorrect manner of wearing the helmet, being loosely fastened, no use of the visor and the helmet having come off during the crash.

Crash severity

Crash severity is an important confounder but seldom controlled for in studies of helmet use and head injuries. Several variables such as the collision type, object of the collision, cost of repairs to the motorcycle and Injury Severity Score (ISS) for injuries other than those to the head (1–8, 9–15 and $\geqslant$16 points)[29,30] were used to indicate the crash severity. The cost of repairs for motorcycle damage (<NT$2000, 2000–4999 and $\geqslant$5000) was estimated by the manager of a local motorcycle body shop. When a subject was recruited, the manager was notified to examine the involved motorcycle by visiting the scene of the crash, a motorcycle body shop or the subject's home in order to estimate the repair cost of the motorcycle. An emergency physician (W-Y.Y) reviewed injured body region(s) and computed the Abbreviated Injury Scale (AIS) and ISS for each subject. The AIS is an ordinal scale of injury severity ranging from 1 (minor injury) to 6 (unsurvivable) for each of six body regions (head, face, chest, abdomen, extremities/pelvis and external skin).[31] The AIS scores of the three most severely injured body regions other than the head were squared and added together to produce the non-head ISS scores.

Validation of exposure information

To validate whether the distribution of helmet types worn by the emergency-room controls represented the prevalence of those helmets on motorcyclists on the roads, information on helmet type was collected from motorcyclists who refuelled at petrol stations in Taichung City. For each case motorcyclist, 10 petrol-station motorcyclists were asked whether they had had a crash in the past year, and if they answered positively, the helmet type and fastening status were determined. The times of the interviews at the petrol stations were matched to the crash time of the cases (i.e. the same day of the week and the same time of the day), and a petrol station nearest to the case crash site was selected. Of 4580 motorcyclists interviewed at 23 petrol stations, 377 had experienced a motorcycle crash in the past year.

To validate the self-reported helmet fit and alcohol consumption at the time of the crash, the occipital–frontal and inner helmet circumferences and blood alcohol concentrations of the case and control motorcyclists were assessed. A helmet was considered to fit poorly when a difference between the two circumferences exceeded 3 cm. A blood alcohol concentration of $\geqslant$50 mg/dl was considered to indicate recent alcohol consumption. In total, the occipital–frontal and inner helmet circumferences of 336 motorcyclists who carried their helmets into the emergency room were assessed, and the blood alcohol concentrations of 679 riders were measured.

Statistical analysis

Distributions of helmet-related characteristics and other categorical variables among the case and control groups were compared using Pearson's chi-squared tests. Furthermore, a conditional logistic regression model was applied to investigate the independent relationships among head injury, helmet type and improper helmet use after adjusting for potential confounders such as age, crash severity and behavioural characteristics. To avoid large type II errors in variable selection, variables with a *P*-value of <0.25 in the bivariable logistic analysis were included in the initial multivariable analysis.[32] Moreover, relationships of helmet type and improper helmet use with severe head injury (i.e. brain injury) were further examined. Since use of an indicator value for missing values to a regression model may introduce bias,[33] our data analyses were limited to complete pairs in which both cases and controls had exposure measurements.

Distributions of helmet types among the emergency-room controls and motorcyclists interviewed at petrol stations were compared using Pearson's chi-squared tests. Kappa statistics were calculated to estimate the measurement reliability of self-reported data on helmet fit and alcohol consumption at the time of the crash. Statistical Analysis Software version 9.1 (SAS Institute, Cary, NC, USA) was used for all statistical analyses.

Results

Of 4191 motorcyclists who sought treatment at the emergency room during the study period, 1428 were diagnosed as having a head injury, of whom 535 sustained brain injuries. After matching the crash time, 458 motorcyclists with head injuries (23 drawn from medical examiner records), including 290 with brain injuries, were successfully matched as the controls.

The distribution of demographic and behavioural characteristics for the 458 cases and 458 controls are shown in Table 1. Compared with case motorcyclists, control motorcyclists were more likely to be younger or older ($P = 0.06$) and unlicensed ($P < 0.001$) and to have lower education levels ($P = 0.007$), higher riding speeds ($P < 0.001$) and positive alcohol consumption at the time of the crash ($P < 0.001$). Furthermore, based on the results of the bivariable logistic regression analyses, unadjusted odds ratios (ORs) and 95% confidence intervals (CIs) of these characteristics as they related to the occurrence of head injuries are also given.

Table 2 shows the distributions of crash severity for case and control motorcyclists. Compared with the controls, case motorcyclists were more likely to have had a head-on collision ($P = 0.007$), to have higher repair costs for motorcycle damage ($P < 0.001$) and higher non-head ISS scores ($P < 0.001$).

Distributions of helmet-related characteristics for the case and control groups are shown in Table 3. Compared with control motorcyclists, motorcyclists in the case group were less likely to have been wearing a helmet ($P = 0.01$) and more frequently wore half-coverage helmets ($P < 0.001$). Among both case and control motorcyclists, half-coverage helmets were most commonly used, followed by full-coverage helmets. Motorcyclists in the case group more frequently used a helmet that cost <NT$300 ($P < 0.001$), had a loosely fastened strap ($P < 0.001$) and lacked a helmet visor ($P = 0.005$) than control motorcyclists. Compared with control motorcyclists, helmets of case motorcyclists were more likely to have been displaced or to have come off in the crash ($P < 0.001$). It was noted that missing values occurred more frequently in the case than in the control motorcyclists for helmet-related characteristics, particularly for the fixation status during the crash (13.7% vs 2.5%).

Table 4 shows the distributions of helmet type by helmet-related characteristics. The three helmet types—full-face, open-face and half-coverage—differed in terms of helmet cost ($P < 0.001$), helmet damage prior to the crash ($P = 0.041$), manner of wearing the helmet ($P < 0.001$), fastening status ($P = 0.021$), helmet visor ($P < 0.001$) and fixation status during the crash ($P < 0.001$).

Table 5 shows the results of the multivariable conditional logistic regression analyses respectively treating all head injuries and only brain injuries as the dependent variable. After controlling for age, motorcycle licensure, riding speed and alcohol consumption at the time of the crash, and cost of repairs for motorcycle damage, compared with helmeted motorcyclists, non-helmeted motorcyclists were more than four times as likely to have head injuries (OR 4.54; 95% CI 1.25–16.5) and more than ten times as likely to have brain injuries (OR 10.4; 95% CI 1.82–59.2). Compared with motorcyclists who wore full-face helmets, those wearing the open-face helmets did not have a significantly increased risk of head injury (OR 1.40; 95% CI 0.78–2.50) or brain injury (OR 1.03; 95% CI 0.44–2.43), and those wearing half-coverage helmets were more than twice as likely to have head injuries (OR 2.57; 95% CI 1.50–4.40) and brain injuries (OR 2.10; 95% CI 1.01–4.38). Compared with motorcyclists whose helmets were firmly fastened, those with loosely fastened helmets had an increased risk of head injury (OR 1.94; 95% CI 1.33–2.82) and were more than twice as likely to have brain injuries (OR 2.50; 95% CI 1.47–4.25).

Of 377 motorcyclists interviewed at petrol stations who had experienced a motorcycle crash in the past year, 1.9% were not wearing a helmet at the time of the crash. Among helmeted motorcyclists, 15.7% were wearing full-face helmets, 28.1% were wearing open-face helmets and 56.2% were wearing half-coverage helmets. The distributions of helmet use ($P = 0.394$) and helmet type ($P = 0.07$) among these motorcyclists did not differ from those of the emergency room controls. Of the petrol-station motorcyclists, 21.5% had loosely fastened helmets; this differed from the 33.8% of emergency room controls ($P < 0.01$) who had loosely fastened helmets.

To test the measurement reliability, kappa values were 0.72 for helmet fitness and 0.65 for alcohol use, indicating a substantial strength of agreement.[34] Distributions of the two measures were similar between the case (0.71 and 0.68) and control (0.73 and 0.63) groups.

Discussion

The results of this case–control study indicate that of the three commonly used helmet types, half-coverage helmets provide the least protection against head injuries for motorcycle riders when a crash occurs, and no significant difference in the protection was detected between full- and open-face helmets. Moreover, improper helmet use may affect helmet fixation in a motorcycle crash and thus reduce the helmet's effectiveness for preventing head injuries.

The better performance of full-face helmets in preventing head injuries over other helmet types may result from coverage of the entire head and the presence of a chin bar. Usually, a motorcycle helmet consists of a hard shell of fibreglass or thermoplastic to reduce the force of a direct blow to the skull, an energy-absorbing foam liner to dissipate deceleration forces and a retention system consisting of a chin

Table 1 Comparison of demographic and behavioural characteristics between case and control motorcyclists

Characteristic	Cases ($n = 458$) *N* (%)	Controls ($n = 458$) *N* (%)	OR[a] (95% CI)
Age in years at the time of injury			
<18	24 (5.2)	13 (2.8)	2.11 (1.06–4.21)
18–35	236 (51.5)	275 (60.2)	1.00
36–55	128 (28.0)	111 (24.3)	1.36 (1.00–1.87)
>55	70 (15.3)	58 (12.7)	1.42 (0.92–2.18)
Gender			
Female	248 (54.1)	273 (59.6)	1.00
Male	210 (45.9)	185 (40.4)	1.26 (0.96–1.67)
Body mass index (kg/m^2)			
Underweight (<18.5)	61 (14.5)	46 (10.6)	1.37 (0.90–2.09)
Ideal (18.5–23.9)	228 (54.2)	245 (56.6)	1.00
Overweight (24.0–26.9)	75 (17.8)	100 (23.1)	0.82 (0.57–1.16)
Obese (⩾27.0)	57 (13.5)	42 (9.7)	1.44 (0.94–2.19)
Educational level			
College or above	109 (25.6)	152 (34.0)	1.00
Senior high	215 (50.5)	222 (49.7)	1.35 (0.98–1.85)
Junior high	45 (10.5)	28 (6.2)	2.14 (1.25–3.68)
Elementary or below	57 (13.4)	45 (10.1)	1.82 (1.11–2.96)
Motorcycle licensure			
Licence for heavy motorcycles	278 (61.9)	354 (77.6)	1.00
Licence for light motorcycles	113 (25.2)	82 (18.0)	1.75 (1.26–2.44)
No motorcycle licence	58 (12.9)	20 (4.4)	3.68 (2.13–6.35)
Safety-related traffic violation in the past year			
Yes	239 (56.2)	272 (60.0)	1.00
No	186 (43.8)	181 (40.0)	1.24 (0.94–1.62)
Riding speed at the time of the crash (km/h)			
⩽30	98 (23.1)	155 (34.3)	1.00
31–50	201 (47.4)	220 (48.7)	1.45 (1.06–2.00)
>50	125 (29.5)	77 (17.0)	2.57 (1.73–3.82)
Alcohol consumption at the time of crash			
Yes	35 (7.7)	3 (0.7)	19.8 (4.47–87.6)
No	421 (92.3)	454 (99.3)	1.00
Engine volume (cm^3)			
⩽50	145 (33.9)	133 (29.4)	1.21 (0.88–1.67)
70–110	109 (25.5)	129 (28.5)	0.93 (0.67–1.29)
⩾125	174 (40.6)	190 (42.1)	1.00

[a]OR and CI from bivariable analysis results of conditional logistic regression.

strap.[35] Most half-coverage helmets do not have a visor, whereas full-face and open-face helmets do have a visor or faceguard to cover the face. Full-face helmets also incorporate a chin bar that extends upwards to a height just below the lips. Half-coverage helmets are cheaper than other helmet types; however, they are less likely to meet national safety standards.[36] There is still much that can be done to reduce head injuries and deaths among helmeted riders, particularly in countries where half-coverage helmets are commonly used (e.g. >60% of Taiwanese in this study).

Table 2 Comparison of crash severity between case and control motorcyclists

Characteristic	Cases ($n = 458$) N (%)	Controls ($n = 458$) N (%)	OR[a] (95% CI)
Collision type			
Rear-end	189 (45.3)	253 (56.1)	1.00
Head-on	172 (41.3)	149 (33.0)	1.51 (1.11–2.04)
Single vehicle	56 (13.4)	49 (10.9)	1.50 (0.97–2.33)
Collision object			
Moving motorcycle	94 (21.8)	115 (25.2)	1.00
Moving car	236 (54.8)	249 (54.5)	1.12 (0.80–1.59)
Other moving objects	17 (3.9)	22 (4.8)	0.96 (0.45–2.05)
Stationary objects	28 (6.5)	21 (4.6)	1.50 (0.78–2.88)
No object hit	56 (13.0)	50 (10.9)	1.40 (0.86–2.28)
Non-head ISS (points)			
1–8	404 (88.2)	438 (95.6)	1.00
9–15	27 (5.9)	17 (3.7)	1.73 (0.92–3.76)
⩾16	27 (5.9)	3 (0.7)	8.93 (2.69–29.7)
Cost of motorcycle repair (NT$)[b]			
<2000	139 (33.3)	239 (53.7)	1.00
2000–4999	90 (21.6)	114 (25.6)	1.36 (0.95–1.96)
⩾5000	109 (26.2)	78 (17.5)	2.43 (1.66–3.55)
Not repairable	79 (18.9)	14 (3.2)	6.86 (3.49–13.5)

[a]OR and CI from bivariable analysis results of conditional logistic regression.
[b]The exchange rate was ~US$1.00 = NT$32.00 at the time of this study.

Our results also reflect the importance of correct helmet use for maximal protection against head injuries. Given the same crash severity, the fixation of a helmet during a crash was most closely related to the retention system. The result of a further subgroup analysis showed that helmet detachment was correlated with the helmet being loosely fastened [point biserial correlation coefficient $(r_{pb}) = 0.64$]. Nevertheless, helmet retention systems are rarely tested in the laboratory or regulated by safety standards, and very few empirical data are available. In many Asian countries, more than one-third of motorcycle riders were found to wear a helmet improperly, such as wearing it unfastened or loosely fastened in order to exhibit 'token' compliance with helmet-use laws, and some even put on a helmet only when the police are nearby.[25] Furthermore, the police seldom enforce proper helmet use.[26] In sum, this study demonstrates for riders, policemen and policymakers that wearing a helmet improperly might not be sufficient to prevent head injuries.

Crash severity is seldom controlled for in studies of helmet use and head injuries. Without controlling for it, such studies implicitly assume similar distributions of crash severities between helmeted and non-helmeted riders, and this assumption is often violated.[37,38] There are no standardized measures of severity for motorcycle crashes. In this study, crash severity was indicated by the cost of repairs to the damaged motorcycle, the type of collision and the object with which the motorcyclist had collided. Motorcycle repair costs might be affected by social and economic factors, and collision type and collision object might not be able to discriminate severity levels among various collision objects or among single-vehicle crashes. A commonly used alternative is a modification of the ISS that calculates injuries to body regions other than the head.[30] However, the non-head ISS index could no better explain the risk of head injury in the regression model, and more importantly, it had to assume that the occurrence of injuries to body regions other than the head was independent of the incidence of head injuries or the use of helmets. In reality, this assumption might not be valid.[39]

There are several limitations to the present study. First, a referral pattern might exist if case and control motorcyclists were not selected from the same population base. Motorcyclists who had serious injuries were probably more likely to have been referred to the study hospital than those with minor or no injuries. For instance, the emergency room controls had a different distribution of helmet-fastening status compared with motorcyclists at petrol stations.

Table 3 Comparison of helmet-related characteristics between case and control motorcyclists

Characteristic	Cases ($n=458$) N (%)	Controls ($n=458$) N (%)	OR (95% CI)
Helmet use[a]			
Helmeted	436 (95.2)	452 (98.7)	1.00
Non-helmeted	22 (4.8)	6 (1.3)	3.50 (1.29–9.54)
Helmet type			
Full-face	50 (11.6)	73 (17.0)	1.00
Open-face	106 (24.7)	149 (34.6)	1.05 (0.65–1.69)
Half-coverage	274 (63.7)	208 (48.4)	2.06 (1.34–3.17)
Helmet ownership			
Driver	367 (90.8)	402 (93.7)	1.00
Other	37 (9.2)	27 (6.3)	1.43 (0.85–2.42)
Helmet fit			
Good fit	379 (94.0)	396 (92.3)	1.00
Poor fit	24 (6.0)	33 (7.7)	0.69 (0.39–1.23)
Helmet cost (NT$)[b]			
<300	194 (57.9)	156 (42.5)	1.96 (1.22–3.16)
300–599	102 (30.5)	150 (40.9)	1.08 (0.65–1.78)
⩾600	39 (11.6)	61 (16.6)	1.00
Manner of wearing helmet			
Covering the whole head	293 (72.9)	302 (70.6)	1.00
Worn on the back of the head	90 (22.4)	104 (24.3)	0.87 (0.63–1.21)
Worn in reverse	19 (4.7)	22 (5.1)	0.81 (0.42–1.58)
Fastening status			
Firmly fastened	222 (51.6)	286 (66.5)	1.00
Loosely fastened	208 (48.4)	144 (33.5)	1.98 (1.47–2.66)
Helmet visor			
Pulled down	136 (33.9)	185 (43.7)	1.00
Not pulled down	63 (15.7)	73 (17.3)	1.17 (0.78–1.77)
Without a visor	202 (50.4)	165 (39.0)	1.70 (1.23–2.36)
Fixation status during the crash			
Fixed on the head	214 (56.9)	351 (82.6)	1.00
Displaced but still on the head	54 (14.4)	47 (11.1)	2.07 (1.27–3.37)
Had come off	108 (28.7)	27 (6.3)	8.12 (4.66–14.1)

[a]Data on non-helmeted motorcyclists are not presented other than 'Helmet use'.
[b]The exchange rate was ~US$1.00 = NT$32.00 at the time of this study.

Nevertheless, the biased direction of the referral pattern may have tended to underestimate the effect of improper helmet use. Second, riders who wore full-face helmets may have been more aware of traffic safety than those wearing half-coverage or open-face helmets. Personality characteristics such as risk-taking were not directly measured and controlled for in the study, although they may have differed among riders who wore different helmet types and with different fastening statuses. Third, information bias might exist because eligible subjects who had serious head injuries were less likely to respond to our interviews, and case motorcyclists were more likely than control motorcyclists to have proxy information and missing values. Accordingly, differential ascertainments of exposure information such as the helmet type and fastening status between the case and control groups might have occurred, and a prospective cohort study to validate these results is warranted. Fourth, to estimate the population-based

Table 4 Distribution of helmet type with other helmet-related characteristics[a]

Characteristic	Helmet type			
	Full-face ($n=123$) N (%)	Open-face ($n=255$) N (%)	Half-coverage ($n=482$) N (%)	P-value
Helmet ownership				
Driver	112 (94.9)	222 (91.4)	435 (92.0)	0.483
Other	6 (5.1)	21 (8.6)	37 (8.0)	
Helmet fit				
Good fit	108 (91.5)	224 (92.2)	443 (94.1)	0.484
Poor fit	10 (8.5)	19 (7.8)	28 (5.9)	
Helmet cost (NT$)[b]				
<300	1 (1.0)	52 (25.4)	297 (75.4)	<0.001
300–599	42 (40.4)	118 (57.5)	92 (23.6)	
⩾600	61 (58.6)	35 (17.1)	4 (1.0)	
Manner of wearing helmet				
Covering the whole head	105 (89.0)	190 (78.2)	300 (63.8)	<0.001
Worn on the back of the head	11 (9.3)	37 (15.2)	146 (31.1)	
Worn in reverse	2 (1.7)	16 (6.6)	23 (5.1)	
Fastening status				
Firmly fastened	80 (65.0)	163 (63.9)	265 (53.8)	0.022
Loosely fastened	43 (35.0)	92 (36.1)	217 (46.2)	
Helmet visor				
Pulled down	69 (59.5)	138 (57.3)	114 (24.3)	<0.001
Not pulled down	36 (31.0)	43 (17.8)	57 (12.1)	
Without a visor	11 (9.5)	60 (24.9)	296 (63.6)	
Fixation status during the crash				
Fixed on the head	88 (75.2)	186 (79.2)	291 (64.8)	<0.001
Displaced but still on the head	8 (6.8)	28 (11.9)	65 (14.6)	
Had come off	21 (18.0)	21 (8.9)	93 (20.6)	

[a]Excluding 28 case–control pairs in which case or control motorcyclists did not wear a helmet.
[b]The exchange rate was ∼US$1.00 = NT$32.00 at the time of this study.

Table 5 Results of a conditional logistic regression analysis treating all head injuries and only brain injuries as dependent variables, respectively

Characteristic	All head injuries[a] OR (95% CI)	Only brain injury[a] OR (95% CI)
Helmet use		
Helmeted	1.00	1.00
Non-helmeted	4.54 (1.25–16.5)	10.4 (1.82–59.2)
Helmet type		
Full-face	1.00	1.00
Open-face	1.40 (0.78–2.50)	1.03 (0.44–2.43)
Half-coverage	2.57 (1.50–4.40)	2.10 (1.01–4.38)
Fastening status		
Firmly fastened	1.00	1.00
Loosely fastened	1.94 (1.33–2.82)	2.50 (1.48–4.25)

[a]Controlled for age, motorcycle licensure, riding speed and alcohol consumption at the time of the crash, and cost of motorcycle repairs.

prevalences of helmet types and fastening statuses, data from petrol station motorcyclists at the time of crash would be more valid than at the study time. However, direct observations at petrol stations may help avoid recall errors, memory lapses and defensive responses. Fifth, missing data on some helmet-related characteristics such as fixation status during the crash were unbalanced between case and control motorcyclists; in addition, only 36.7% of motorcyclists (39.3% of cases and 32.3% of controls) carried their helmets into the emergency room. Further analyses showed that motorcyclists who had missing values for the fixation status during the crash or those who did not carry their helmets tended to have higher non-head ISS scores or higher repair costs for motorcycle damage (i.e. higher levels of crash severity). Since the repair cost for motorcycle damage was controlled for in the statistical analysis, a potential bias in the result due to this selecting factor should have been avoided. Finally, there was a possibility of misdiagnosing motorcyclists who consumed alcohol as having head injuries. Nevertheless, the proportion of motorcyclists who consumed alcohol at the time of the crash was very low in the study.

This study demonstrates that the type and fastening status of a helmet can affect the helmet's effectiveness in preventing head injuries. For a long time, injury prevention workers have focused on whether or not motorcycle riders wear a helmet, rather than on which helmet type should be worn or how the helmet is worn. Now it is high time to promote legislation that requires motorcycle riders to wear safer helmets (e.g. full-face helmets) as well as to fasten the helmets properly.

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KEY MESSAGES

- Among full, open-face and half-coverage helmets, the latter gave motorcyclists the least protection from head injuries.
- Improper helmet use may affect helmet fixation in a crash and thus reduce the helmet's effectiveness for preventing or reducing head injuries.
- It is time to promote legislation that requires motorcyclists to wear safer helmets and to fasten the helmets properly.

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