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Powered paragliding accidents and injuries: a cross-sectional study to investigate this extreme sport's risks

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Powered paragliding accidents and injuries: a cross-sectional study to investigate this extreme

sport's risks

ABSTRACT

Background/Aim -

Powered paragliding is usually confused with paragliding or considered a variation of this sport. However, there are distinct differences between the two sports; the use of a motor in powered paragliding results in a different manner of flying, and allows the sport to be practised in different environments. There are no existing studies in literature on the traumatology of powered paragliding, and we hypothesised that the differences between these two sports result in different types of injuries.

Methods -

To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

Results -

Powered paragliding accidents occur in different phases of flight from those of paragliding (takeoff vs. landing) and the pattern of injuries is different: the upper limbs are most affected, whereas spinal injuries are less frequent.

Some kinds of injuries, such as burns or hand injuries due to the contact with the propellor, are specific to this sport.

Finally, contrary to the belief held up to now by experts of this sport, the number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions -

The results of this study suggest that in future this sport should be studied using studies and case reports distinct from those of paragliding. Furthermore, to prevent certain injuries specific to powered paragliding, various types of safety gear and equipment should be recommended or made obligatory for those practising this sport.

Strengths and limitations of this study

The first study in literature on powered-paragliding

A large amount of data (384 incident reports) collected prospectively from 1995 to 2012

This study is based on incident reports filed by participants or witnesses.

A specific form inclusive of detailed injury informations (body part affected, severity of the injury, medical assistance, extensive description of the event and its consequences) was used to collect data.

New findings

1. Power paragliding is a very different sport from paragliding, and accidents occur more frequently during takeoff than landing.
2. The motor may aggravate the dynamics of powered paragliding accidents, making falls into water particularly dangerous, and causing characteristic injuries such as burns.
3. Compared to paragliding, the upper limbs are the body area most prone to injury in powered paragliding; certain injuries such as hand trauma due to contact with the motor propellor are specific to powered paragliding, and the use of protective devices is therefore recommended.
4. Although powered paragliding is generally considered safer than paragliding, in this study the ratio of fatal accidents to total accidents was comparable to those reported in literature for paragliding.

Introduction

Powered paragliding or paramotor (PPG) is a sport in which the pilot flies by means of a wing similar to that of paragliding (P), the sport from which it derives, under which the crew is suspended by means of long lines. It is a completely different sport from P because the equipment used includes a motor worn on the back and held in place by a harness (Fig. 1).

Compared to other aerial sports, P nevertheless remains the most similar to PPG: both require the pilot to keeps the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much so that various national and international competitions have been held throughout the world over the last few years.

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. A knowledge of accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine to provide an insight into the types of conduct, protective clothing and safety systems to adopt to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies of this sport in medical literature: in a recent literature review [1], this sport is only mentioned among the variations of P, with which it is normally grouped together.

Given that the way of flying a paramotor is very different to that of a paraglider, we hypothesised that the accident and injury types differ greatly between the two sports as a result.

The aim of this study is to clarify the dynamics of paramotoring accidents, the conditions in which these occur, the type of injuries sustained, and to highlight any differences with respect to P.

Materials and methods

We analysed the 384 incident reports of the accidents arising between 1995 and the end of 2012 (the start date of the present study), that the US Powered Paragliding Association (USPPA) collected prospectively using a form published on its website.

The forms submitted had been completed by the pilot involved, a witness who had seen the accident, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields and consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information, including demographic information and details of the pilot's PPG experience;

3-Details of the accident, including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information, including details of any injuries, the body part affected, severity of the injury, any medical assistance sought and/or collateral damage to persons or things.

5-Narrative, an extended description of the event and its consequences.

This final section has been very useful for our work; having read all the reports individually, the majority provide valuable information, particularly with regard to the medical consequences of the accidents.

The data published by the USPPA is public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data was analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi -square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[10-12].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score: a 7-point system (table 1) developed to assess the severity of injuries and diseases sustained or developed during aviation accidents. Based on the available data, nevertheless, it was not possible to distinguish between classes V and VI in all cases.

Table 1: NACA Score

Category	Description	Example
NACA 0	No injury or disease.	
NACA I	Slight injury or illness. No acute medical intervention necessary.	E.g. slight abrasion.

NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical investigation, but usually no emergency medical measures necessary.	E.g. fracture of a finger bone, moderate cuts, dehydration.
NACA III	Moderate to heavy but not life-threatening disorder. Frequently emergency medical measures on the site	E.g. femur fracture, milder stroke, smoke inhalation
NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	E.g. vertebral injury with neurological deficit, severe asthma attack; drug poisoning
NACA V	Acute vital (life threatening) danger	E.g. third grade skull or brain trauma, severe heart attack, significant opioid poisoning
NACA VI	Breath and/or cycle stop and/or reanimation	---
NACA VII	Death	---

Both categories cover conditions posing an immediate threat to life and requiring immediate emergency medical assistance: therefore we have decided to consider them as a single category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and divided these into 3 classes based on the severity of the injuries:

1-minor (NACA I, II), usually not requiring emergency medical measures

2-major (NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal (NACA VII).

We associated the incidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

The pilots involved in power paragliding accidents were aged between 24 and 72(average age= 44.46, median= 48, SD= 9.542).

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The number of incident reports/year is shown in table 2.

Table 2. Accidents/Year

Year	Number of Reports
1995	1
1996	1
1998	1
2000	2
2001	10
2002	10
2003	18
2004	30
2005	56
2006	57
2007	42
2008	42
2009	30
2010	31
2011	24
2012	29

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1). Only three incidents involved a female pilot.

Pilot injuries were classified according to NACA category (table 3): 23 incidents were fatal.

Table 3.NACA Score of PPG accidents in this study

NACA Category	Pilots	%
0	194	50,6
I	59	15,4
II	48	12,5
III	43	11,2

IV	11	2,9
V + VI	5	1,3
VII	23	6

The following factors were taken into consideration: the experience of the pilots involved (table 4), the type of terrain in the takeoff/landing areas (table 5), the phase of flight during which the accident took place (table 6), the primary cause (table 7) and the type of accident (table 8).

Table 4. Pilot Rating

Pilot Rating	**count**	**%**
Not Applicable	45	11,7
None	49	12,8
Student	16	4,1
PPG1	52	13,5
PPG2	98	25,5
PPG3	58	15,1
Instructor	35	9,1
Unknown	23	6
Other	7	

Table 5. Terrain in which accidents occurred

Terrain	**Tot**	**%**
Flat	270	70,5
Not Applicable	44	11,4
Hilly	34	8,8
Water	10	2,6
Mountainous	10	2,6
Unknown	10	2,6
Other	5	1,3

Table 6. Phase of Flight

Phase of Flight	Count	%
Takeoff	126	32,8
Inflation	22	5,7
Runup	17	4,4
Not Applicable	30	7,8
Cruise	107	27,9
Landing	24	6
Approach	26	6,7
Other	26	6,7
After Landing	5	1,3

Table 7. Primary cause of accidents

Primary cause	Tot.	%
Pilot Error on Launch	71	18,5
Pilot Error In Flight	85	22,1
Mechanical Failure Powerplant/Propeller	49	12,7
Pilot Error Preflight/Postflight	38	9,9
Other	23	6
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5,7
Pilot Error and Weather	17	4,4
Pilot Error and Mechanical Failure	17	4,4
Not Applicable	17	4,4
Pilot error on landing	11	2,9
Mechanical Failure/Wing	8	2
Unknown	7	1,8

Wake	6	1,6
Mechanical Failure/harness	5	1,3
Fuel Exhaustion	5	1,3
Tight takeoff/LZ Area	2	0,5

Table 8. Type of accidents

Type of incident	**Tot.**	**%**
Collision with Terrain/Obstruction on Ground	76	19,8
Powerplant Equipment Malfunction	58	15,1
Body contact with spinning prop	43	11,2
Hard Landing	40	10,4
Fall	37	9,7
Wing Malfunction or Deflation	35	9,1
Other	29	7,5
Handling	20	5,2
Line Tangle/Damage	15	3,9
Collision with other Aircraft/Ultralight	14	3,6
Water Immersion	10	2,6
Not Applicable	6	1,5

Out of 383 accidents, 217(56.6%) pilots sustained no injuries, 118(30.8%) a single injury, 39(10.2 %) multiple injuries, while five (1.3%) suffered systemic medical conditions; in particular two pilots suffered generalised burns, two sustained multiple injuries and one drowned (table 9).

Table 9. Medical consequences in 166 non-fatal accidents in our study.

Body Area Affected	**Injury Type**	**No. Cases**	**Tot.**
Head	Concussion	2	3
	Open Wounds	1	
Neck	Fractures (C2)	1	1

Chest	Fractures (Ribs)	1	2
	Contusions	1	
Shoulder	Open Wounds	4	17
	Fractures	6	
	Lacerations	1	
	Bruising	4	
	Dislocation	2	
	Sprain	1	
	Strain/muscle rupture/tear	1	
	Tendon Injury	1	
	Other	2	
Arm	Contusion	2	7
	Open Wounds	1	
	Fracture	1	
	Laceration	3	
Forearm	Unknown	1	1
Wrist	Fracture	1	1
Hand	Fracture	6	27
	Fracture With Amputation	11	
	Open Wound	6	
	Laceration	2	
	Strain/muscle rupture/tear	1	
	Contusion	1	
Abdomen	Contusion	1	1
Back	Other	1	13
	Fractures	4	
	Strain/muscle rupture/tear	1	

	Contusion	1	
	Unknown	6	
Pelvis	Fracture	1	1
Thigh	Fracture	2	3
	Open Wound	1	
Knee	Unknown	1	12
	Contusion	2	
	Ligamentous rupture	2	
	Dislocation	1	
	Strain/muscle rupture/tear	1	
	Sprain	4	
	Ligamentous rupture and torn meniscus	1	
Calf	Lacerations	1	7
	Fracture	4	
	Wound	1	
	Contusion	1	
Ankle	Fracture	4	17
	Sprain	6	
	Dislocation	1	
	Unknown	2	
	Contusion	3	
	Ligamentous rupture	1	
Foot	Contusion	1	5
	Fracture	2	
	Other	1	
	Unknown	1	
Back, Calf, Ankle, Foot	Fractures		

Face, Wrist, Forearm **Back, Thigh, Spinal**	Fractures Fractures	
Face, Shoulder, Pelvis	Fractures, Tendon rupture, Ligament Injuries	
Chest, Thigh, Knee	Fracture, Contusions	
Face, Arm	Fracture Lacerations	
Back, Wrist, Hand, Pelvis, Ankle, Foot, Knee	Other	
Face, Back, Shoulder	Other	
Neck, Back, Shoulder, Arm, Elbow, Forearm	Burns	
Arm, Thigh, Calf, Forearm	Exposed Fracture, Burns	
Face, Shoulder, Arm, Knee	Lacerations	
Face, Arm, Thigh	Lacerations	
Forearm, Wrist, Hand, Foot	Lacerations	
Neck, Shoulder	Unknown	
Back, Foot	Unknown	
Chest, Thigh	Open Wounds	
Arm, Pelvis, Calf	Fracture, Dislocation	
Wrist, Hand	Contusion	
Shoulder, Arm, Pelvis	Contusion	
Pelvis **Shoulder And Arm**	Strain/muscle rupture/tear, Tendon rupture	
Head, Face, Pelvis	Concussion, Fracture, Internal Bruising	
Back, Ankle	Fracture, Sprain, Bruising	
Elbow, Forearm, Thigh, Calf	Open Wound, Lacerations	
Face, Arm, Calf	Burns	
Pelvis, Back	Fractures	39
Wrist, Arm, Hand	Sprain	
Arm, Knee	Lacerations	

Chest, Arm **Arm, Forearm, Wrist**	Burnt Fracture	
Calf, Ankle, Foot, Knee	Unknown	
Chest, Back, Shoulder, Arm, Elbow, Forearm, Thigh, Knee	Abrasions	
Back, Thigh	Unknown	
Arm, Elbow, Calf Ankle	Burns, Open Wound, Sprains	
Forearm, Thigh, Calf	Soft Tissue, Burns	
Head, Arm, Hand	Unknown	
Back, Shoulder, Arm, Abdomen	Open Wound, Soft Tissue	
Head, Back, Forearm, Wrist, Thigh, Calf, Knee, Foot	Contusions	
Chest, Arm, Calf	Unknown	
Head, Shoulder, Arm, Elbow, Forearm	Unknown	
Multiple trauma		2
Generalised burns		2
Drowning		1
Unknown		4

To identify the areas of the body most affected and therefore most critical for the development of protective clothing, we calculated the number of injuries sustained in each body area (table 10). Out of a total of 252 injuries, the areas of the body most affected were the upper limbs (43.2%) followed by the lower limbs (32.5%) and the spine (10.3%)(table 11).

Table 10. Distribution of the injuries sustained in the different body regions in power paragliding as emerged from this study.

Body region	**Body area affected**	**No. Cases**	**Tot.**	**% of injury total**
Head	Head	7	18	7.1%
	Neck	3		

	Face	8		
Chest	Chest	7	7	2.7%
Upper Limb	Shoulder	27	109	43.2%
	Arm	26		
	Forearm	11		
	Wrist	8		
	Elbow	5		
	Hand	32		
Abdomen	Abdomen	2	2	0.7%
Spine	Spine	26	26	10.3%
Pelvis	Pelvis	8	8	3.2%
Lower Limb	Thigh	13	82	32.5%
	Knee	19		
	Calf	17		
	Ankle	22		
	Foot	11		

Of the twenty-three fatal accidents, five were the result of an involuntary landing in water: one autopsy revealed the cause of drowning to be head injury with haemorrhage and loss of consciousness.

Another two accidents were fatal due to cerebral spine fractures with spinal cord damage.

In four cases, death was caused by severe head trauma. In all remaining cases, death was the result of high-energy multi-trauma, although the reports do not allow us to identify the precise injuries responsible for death, even if this were possible.

Distribution of the accidents which caused injuries in the three classes minor, major and fatal is shown in Fig. 2. The relationship between accident severity and the phase of flight in which these took place is described in Table.11.

Table 11. Relation between accident severity and phase of flight.

Phase of flight	**Count**	**Minor (NACA I, II)**	**Major (NACA**	**Fatal (NACA VII)**

			III,IV,V,VI)	
takeoff	70	64,3%	28,6%	7,1%
cruise	37	54,0%	21,7%	24,3%
other	16	56,3%	18,8%	25,0%
approach	15	46,6%	40,0%	13,3%
landing	15	73,3%	26,7%	0,0%
not applicable	13	46,2%	30,8%	23,1%
inflation	11	54,5%	45,5%	0,0%
runup	10	20,0%	80,0%	0,0%
after landing	2	50,0%	50,0%	0,0%

The relationship between accident severity and accident dynamic is detailed in table 12.

Table 12. Relationship between accident severity and accident dynamic.

Type of incident	count	minor (NACA I, II)	major (NACA III,IV,V,VI)	fatal (NACA VII)
collision with terrain/obstruction on ground	48	62,5%	18,8%	18,8%
body contact with spinning prop	36	44,4%	55,6%	0,0%
hard landing	27	74,1%	22,2%	3,7%
fall	22	54,5%	40,9%	4,5%
wing malfunction or deflation	16	31,2%	56,2%	12,5%
handling	13	53,8%	23,1%	23,1%
water immersion	7	14,3%	14,3%	71,4%
powerplant equipment malfunction	6	100,0%	0,0%	0,0%
other	5	80,0%	0,0%	20,0%
collision with other aircrafts/ultralight	5	40,0%	40,0%	20,0%
line tangle/damage	4	100,0%	0,0%	0,0%

The statistical correlation between injury severity and type of incident (chi-square, $p < 0.001$; confidence 95%) is shown in Fig. 3. The correlation between accident severity and pilot rating is scarcely significant (chi-square, $p=0.044$; confidence 95%).

The data on the collateral damage from the various accidents reveals that in addition to the 383 pilots directly involved, seven bystanders and sixteen pilots of other aircraft involved in collisions were also injured, for a total of 406 persons. The data was insufficient to precisely classify the severity of the injuries suffered by these persons. No injuries were sustained in thirteen cases.

A paramotor instructor was struck on the right hand by a pilot's propellor, with lesion of the ulnar artery and various fractures.

A bystander was struck on the right foot, with the amputation of three toes and injury to the remaining two. A spectator struck by the propellor of a PPG sustained severe facial injuries and another sustained minor injuries to the eye area.

Another bystander suffered amputation of the last three fingers of his left hand after being struck by a paramotor propellor.

A bystander was hit during a hard landing, suffering a minor injury to the forearm.

A power-paraglider pilot was struck by a PPG which was taking off, with the loss of a tooth, and two passengers of a hot air balloon hit during flight by a PPG sustained unknown but minor injuries, as did a power paraglider pilot hit by another PPG.

Discussion

A careful review of the literature indicates that this is the first study of PPG accidents.

In 2007 it was estimated that the sport was practised only in the United States, by just 3000 persons [2].

It would seem to be a prevalently male sport, judging from the clear prevalence of male compared to female members of the association(USPPA) (table 13), a fact also reflected in the low number of women involved in the accidents examined in our study.

Table 13. No. USPPA members/year

Year	**Members**	**F**	**M**
2009	458	10	448
2010	521	10	511
2011	506	8	506
2012	608	17	591
2013	672	18	654

No statistically significant correlation was found in our sample between accident severity and pilot rating (chi-square, p= 0.044).

The majority of the accidents in our study (70.5 %) occurred while flying over level ground. As opposed to P, which is practised over hilly or mountain areas because it requires a descent in order to take off, the paramotor pilot can take off on level ground thanks to the thrust of the motor. It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steadier.

Furthermore PPG differs from P in that the thrust of the motor allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Indeed, power-paragliders[2] widely consider their sport to be much safer than paragliding.

The motor makes it possible to fly frequently and in a much wider variety of weather conditions, so pilots are less inclined to risk flying in extreme and hazardous conditions.

In our study, the weather conditions were a main or contributing cause of accidents in 9.6% of cases: weather conditions alone were the cause in 5.7% of cases, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than that reported in paragliding by Zeller[3], who cite adverse weather conditions as a cause in 19% of paragliding accidents.

Nevertheless, our study clearly shows that use of a motor has an enormous influence on accident dynamics. It can itself be the cause of accidents, it can be an important aggravating factor in the case of an accident, or be the direct cause of injuries.

Our study data showed that the majority of accidents occurred during takeoff (32.9%, or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase of the flight is landing[2, 3].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the motor, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the motor results in the pilot moving away from the ground slowly, as opposed to P, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than with a P, limiting the possibility of adopting emergency manoeuvres and making use of an emergency parachute impossible.

The use of a motor can be the direct cause of accidents distinctive to PPG: the two causes listed as “fuel exhaustion” and “mechanical failure: power-plant/propeller” were responsible for 14% of accidents.

The motor may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant vary between 20 and 40 kg. In the case of collision, both of these factors synergise to make the impact more traumatic given that motor displacement varies between 80cc and 250cc and motor power varies between 11 to 22.5kW; motor thrust is highest during takeoff: the phase of flight when PPG accidents occur most frequently.

In certain reports it is explicitly mentioned that it was precisely the energy supplied to the motor which rendered the impact fatal.

Various reports also describe the perilousness of a state of mental confusion suffered by the pilot during the execution of acrobatic stunts. Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration (increased by the thrust of the motor) hinder blood supply to the brain, with a high risk of suffering blackouts - or in any case a momentary state of mental confusion-at a time when the maximum level of attention is required.

In the case of immersion in water, the weight of the motor tends to drag the pilot rapidly under the surface, without giving him time to free himself from the equipment, making this type of accident particularly feared among paramotor pilots. In our study, this dynamic was responsible for 21.7 % of fatal accidents (71.4% of incidents involving water immersion were fatal: Fig. 3) and a serious (non-fatal) case of near-drowning. It is therefore inadvisable to paramotor over or near water; it is essential that pilots wishing to do so adopt the use of self-inflating and specially designed safety systems (Agama).

PPG differs from P[3, 4, 5, 6, 7] in that the upper limbs are more frequently affected (table 14), while spinal injuries are less frequent.

Table 14. Distribution of the injuries sustained in the different body regions as per the studies on paragliding; modified from[4].

Study	Head	Upper Limb	Lower Limb	Spine
Krüger-Franke et al. (1991) [5]	6.80%	17.10%	31.50%	44.60%
Zeller et al. (1992)[3]	5.40%	17.30%	46.10%	31.10%
Fashing et al. (1997)[6]	16.30%	14.40%	36.50%	32.70%
Rekand (2009)[7]	13.30%	0.00%	26.70%	60.00%

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew due to the thrust of the motor and the weight of the equipment.

The motor is undoubtedly the factor which distinguishes PPG from P in terms of injury type;

contact with the propellor caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands, wrists, forearms, arms and shoulders, as well as all eleven fractures with loss of fingers cited in this study (Fig. 4, Fig. 5, Fig. 6). Contact with incandescent motor parts was the cause of four cases of burns to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burns were the result of actual fires caused by combustion of the motor fuel. In another case, electrical burns to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in P also, while burns resulting from motor fuel combustion or contact with the motor are limited to PPG.

PPG is widely believed to be safer than P, and fatal events considered to be rarer than in P[2].

In our study, 6% of accidents were fatal (fatal accidents/no. Accidents: 23/383). This figure is not lower than the values cited in literature for P and hang-gliding (table 10) and is in any case comparable with the 6.1% of fatal paragliding accidents reported by Schulze (2002)[8] in a study very similar to ours, since it was conducted using the data from incident reports.

Considering the differences between PPG and P, future studies of this sport and related injuries should be conducted separately from P, in separate case studies.

Certain types of safety clothing and equipment can significantly reduce various risks specific to this sport. The use of protective gloves in particular can protect against hand injuries caused by contact with the spinning prop.

Since many prop strike injuries have been higher up the arm where gloves would not be effective, an even better solution could be to add the so called "safety ring" to the motor cage. The safety ring is an aluminum ring that mounts just forward of the radial arms with the same radius as the prop. The safety ring makes it difficult to an open human hand from going into the prop at full rated thrust and adds very little in terms of expense, and weight to the paramotor. Its use should be made obligatory, given that these injuries are often severe, in some cases involving amputation of the fingers. Given the extreme danger of water immersion, it is essential that pilots equip themselves with an Agama when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the motor is vital, given that its malfunctioning is a major cause of accidents.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of P: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the motor and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[2], the number of fatal accidents/number of accidents is not lower than those which occur in P and in hang-gliding[5, 6, 8, 9](table 15).

Table 15. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	Study	No. fatalities	No. participants	% Fatal events
Paragliding	Krüger-Franke et al. (1991)[5].	2	218	0.91%
Paragliding	Schulze et al. (2002)[8].	25	409	6.10%
Paragliding	Fashing et al. (1997)[6]	0	70	0.00%
Hang-gliding	Foray et al (1991)[9].	7	200	3.50%

For these reasons, PPG should be studied separately from P in distinct studies and case reports. Further studies will be useful to confirm the data from this study: we can nevertheless assert that safety equipment such as protective gloves, a safety ring or an Agama, and periodical checks of the motor can reduce certain risks specific to this sport.

Contributorship Statement

The study was conceived by Francesco Feletti and Jeff Goin.
Jeff Goin collected data.
Francesco Feletti carried out statistical analyses and wrote the draft of the manuscript. All authors contributed to critical revisions of the manuscript and approved the final version.

Data sharing statement No additional data are available.

Competing interests None.

Funding statement
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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2. Severity of injuries summary

Fig. 3: Severity of injuries by type of accident

Fig. 4: Serious hand lesions caused by contact with the motor prop: these injuries are specific to powered paragliding.

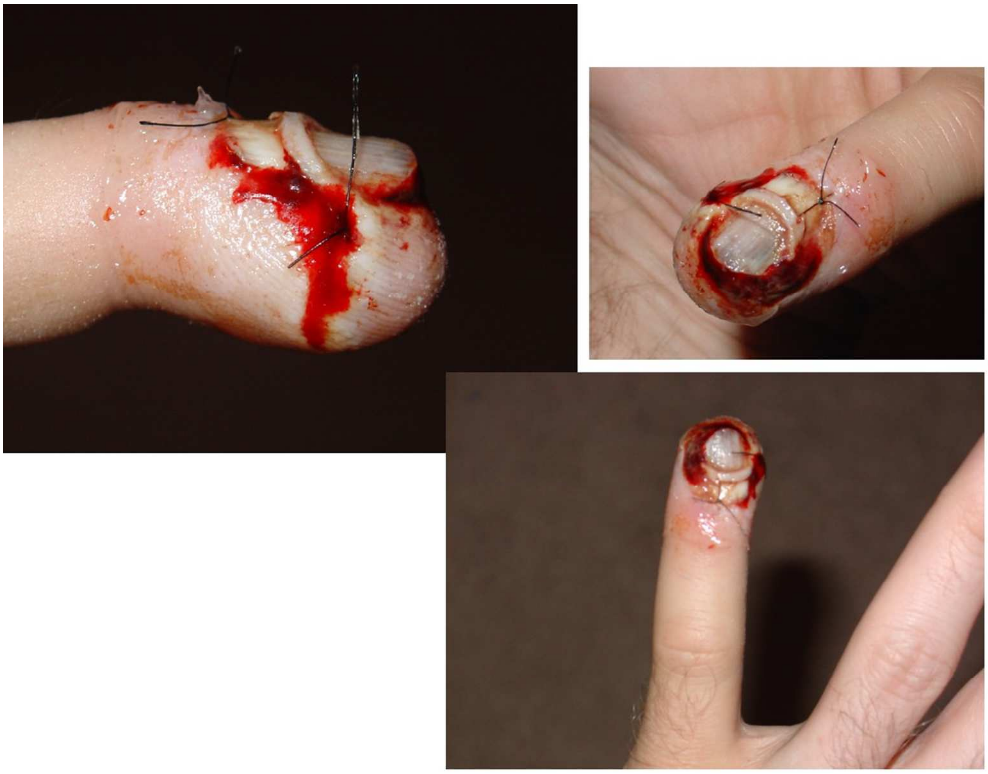
Fig. 5: Serious hand lesions caused by contact with the motor prop.

Fig. 6: Lesion of a finger caused by contact with the motor prop.

Figure 1: Paramotor in flight
134x101mm (300 x 300 DPI)

56x42mm (180 x 180 DPI)

90x67mm (300 x 300 DPI)



152x117mm (200 x 200 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

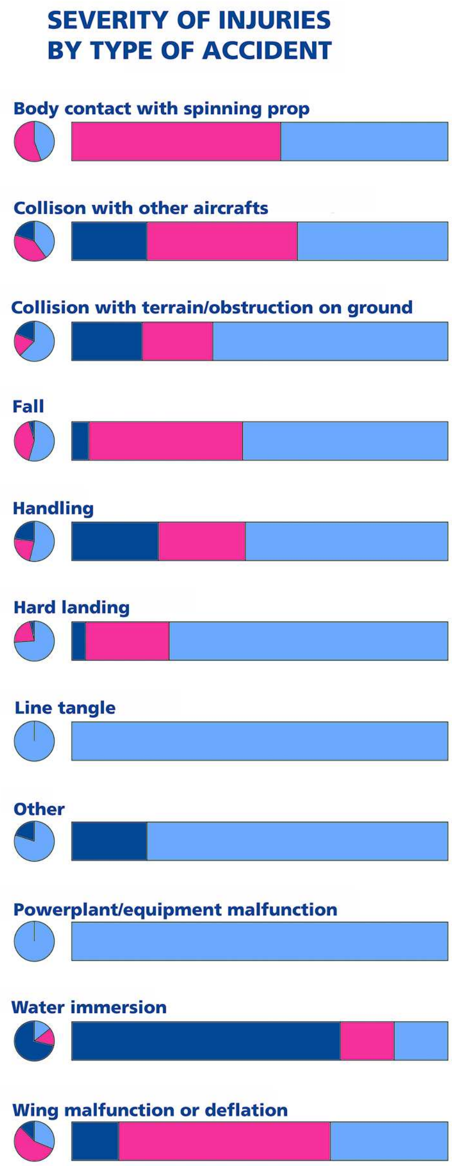
	Item No	Recommendation
Title and abstract **Yes**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **Yes**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **Yes**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **Yes**	4	Present key elements of study design early in the paper
Setting **Yes**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **Yes**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **Yes**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **Yes**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias **Yes**	9	Describe any efforts to address potential sources of bias
Study size **Yes**	10	Explain how the study size was arrived at
Quantitative variables **Yes**	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **Yes**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **Yes**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **Yes**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **Yes**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **Yes**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses **Yes**	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results **Yes**	18	Summarise key results with reference to study objectives
Limitations **Yes**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **Yes**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **Yes**	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding **Yes**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.



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BMJ Open

Accidents and injuries related to powered paragliding: a cross sectional study

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Keywords

Extreme Sports, Sporting injuries, Protective clothing, Motor sports, Injury prevention

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding is a clearly distinct sport from paragliding, mainly because of the use of an engine. We supposed that the differences between these two sports result in different types of injuries.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1).

Outcome: to identify he most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs (44.5%) followed by the lower limbs (32 %), the back (9,8,%), the head (7%), the pelvis (3,1), the chest (2,7%) and the abdomen (0,7%) ($p < 0,001$).

The engine caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help to prevent the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in future this sport should be studied using studies and case reports distinct from those of paragliding.

Strengths and limitations of this study

This is the first study in literature on powered-paragliding.

We analyzed a large amount of data (384 incident reports) collected from 1995 to 2012.

means of long lines. It is a completely different sport from paragliding because the equipment used includes a engine worn on the back and held in place by a harness (Fig. 1).

In contrast to paragliding, which is practised over hilly or mountain areas, because it requires a descent in order to take off, the PPG can take off from level ground thanks to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG: both require the pilot to keeps the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much so that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised only in the United States, by just 3000 persons [1].

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. A knowledge of accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine to provide an insight into the types of conduct, protective clothing and safety systems to adopt to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies of this sport in medical literature except from a case we have previously reported [2]: in a recent literature review [3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that the accident and injury types differ greatly between the two sports as a result.

The aim of this study is to clarify the dynamics of paramotoring accidents, the conditions in which these occur, the type of injuries sustained, and to highlight any differences with respect to paragliding.

2012 (the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but since USPPA is very popular among powered paragliders worldwide, also accidents from other countries were reported.

The forms submitted had been completed by the pilot involved, a witness who had seen the accident, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields and consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information, including demographic information and details of the pilot's PPG experience;

3-Details of the accident, including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extended description of the event and its consequences.

In the form, a specific question on the quality of injuries was missing, but a careful reading of the narrative section allowed to obtain these informations from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score: a 7-point system (table 1) developed to assess the severity of injuries and diseases sustained or developed during aviation accidents. Based on the available data, nevertheless, it was not possible to distinguish between classes V and VI in all cases.

NACA 0		
NACA I	Slight injury or illness. No acute medical intervention necessary.	E.g. slight abrasion.
NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical investigation, but usually no emergency medical measures necessary.	E.g. fracture of a finger bone, moderate cuts, dehydration.
NACA III	Moderate to heavy but not life-threatening disorder. Frequently emergency medical measures on the site	E.g. femur fracture, milder stroke, smoke inhalation
NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	E.g. vertebral injury with neurological deficit, severe asthma attack; drug poisoning
NACA V	Acute vital (life threatening) danger	E.g. third grade skull or brain trauma, severe heart attack, significant opioid poisoning
NACA VI	Breath and/or cycle stop and/or reanimation	---
NACA VII	Death	---

Both categories cover conditions posing an immediate threat to life and requiring immediate emergency medical assistance: therefore we decided to consider them as a single category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and divided these into 3 classes based on the severity of the injuries:

1-minor (NACA I, II), usually not requiring emergency medical measures

2-major (NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal (NACA VII).

We associated the incidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

the accidents examined in our study.

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1). Only three incidents involved a female pilot.

Pilot injuries were classified according to NACA category (table 2): 23 incidents were fatal.

Table 2.NACA Score of PPG accidents in this study

NACA Category	Pilots	%
0	194	50,6
I	59	15,4
II	48	12,5
III	43	11,2
IV	11	2,9
V + VI	5	1,3
VII	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place (table 3), the primary cause (table 4) and the type of accident (table 5).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25,5% PPG2, 13,5% PPG1, 15,1% PPG3, 9,1% Instructor, 12,8% None, 11,7% Not applicable, 6% Unknown, 1,8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating (chi-square, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70,5% flat terrain, 11,4% not applicable, 8,8% hilly terrain, 2,6% water, 2,6 % mountainous terrain, 2,6% unknown data, 1,3% other.

Landing (including approach and after landing)	**55**	**14,3%**
Not Applicable/Other	**56**	**14,6%**

Table 4. Primary cause of accidents

Primary cause	**Tot.**	**%**
Pilot Errors (only)	205	53,5
Mechanical Failure (including fuel exhaustion)	67	17,5
Pilot Error & Weather	17	4,4
Pilot Error & Mechanical Failure	17	4,4
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5,7
Not Applicable/unknown	24	4,4
Other (including wake Tight takeoff/LZ Area)	31	1,8

Table 5. Type of accidents

Type	**Tot.**	**%**
Collision with Terrain/Obstruction on Ground	76	19,8
Powerplant Equipment Malfunction	58	15,1
Body contact with spinning prop	43	11,2
Hard Landing	40	10,4
Fall	37	9,7
Wing Malfunction or Deflation	35	9,1
Other	29	7,5
Handling	20	5,2
Line Tangle/Damage	15	3,9

single injury, 39 (10.2 %) caused multiple injuries, while five (1.3%) caused systemic medical conditions; in particular two pilots suffered generalised burnings, two sustained severe polytrauma and one drowning.

To identify the most affected body areas and therefore most critical areas for the development of protective clothing, we calculated the number of injuries sustained in each body area (table 6). On a total of 256 injuries, the most affected body areas were the upper limbs (44.5%) followed by the lower limbs (32 %) and the back (9,7 %).

Table 6. Distribution of the injuries sustained in the different body regions in power paragliding as emerged from this study.(chi -square , p < 0,001).

Body region	Body area	No. Cases	Types of Injury (number of cases)	Tot	% of all injuries
Head	Head	7	Concussions(3), unknown(2), contusions(1), open wounds(1)	18	7%
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds (1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3),tendon injuries (3),dislocations (2),lacerations (2),unknown (2),abrasions (1),burnings (1),contusions (1),muscle strains (1), sprains (1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11 with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9,7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1),	8	3.1%

	Calf	17	Fractures(7), burnings(2), contusions(2), lacerations(2), unknown(2), wounds(2)		
	Ankle	22	Sprains(8), fractures(5), contusions(3), unknown(3), dislocations(1), ligament ruptures(1), other(1)		
	Foot	11	Fracture(3), unknown(3), contusions(2), other(2), lacerations(1)		

Of the twenty-three fatal accidents, five were the result of an involuntary landing in water: one autopsy revealed the cause of drowning to be head injury with haemorrhage and loss of consciousness.

Another two accidents were fatal due to cerebral spine fractures with spinal cord damage.

In four cases, death was caused by severe head trauma. In all remaining cases, death was the result of high-energy multi-trauma, although the reports do not allow us to identify the precise injuries responsible for death, even if this were possible.

Most of the injuries were minor ones (NACA I-II) followed by major ones(NACA III-VI) and fatals ones (NACA VII).

No significant difference in the distribution of fatal, major and minor injuries among the three main phases of flight (takeoff including inflation and runup, cruise and landing including approach) was found.

With regard to the relationship between accident dynamic and accident severity, body contact with spinning prop and wing malfunction/deflation prevalently caused major injuries (NACA III-VI), representing respectively 55,6% and 56,2% of the injuries causes.

Accidents due to water immersion were prevalently fatal (71,4%).

The other dynamics of injuries cause mainly minor injuries (NACAI-II).

The statistical correlation between injury severity and type of incident (chi-square, $p < 0.001$; confidence 95%) is shown in Table. 7.

Table 7. Severity of Injuries by Type of Incident

Type of incident	Minor (%)	Major (%)	Fatal (%)
Collision with Terrain/Obstruction on Ground	62,5	18,8	18,8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44,4	55,6	0

Handling	53,8	23,1	23,1
Line Tangle/Damage	100	0	0
Collision with other Aircraft/Ultralight	40	40	20
Water Immersion	14,3	14,3	71,4
All Types of Incident	**56,6**	**31,2**	**12,2**

The correlation between accident severity and pilot rating is scarcely significant (chi-square, p=0.044; confidence 95%).

The data on the collateral damage from the various accidents reveals that in addition to the 383 pilots directly involved, seven bystanders and sixteen pilots of other aircraft involved in collisions were also injured, for a total of 406 persons. The data was insufficient to precisely classify the severity of the injuries suffered by these persons. No injuries were sustained in thirteen cases.

A paramotor instructor was struck on the right hand by a pilot's propellor, with lesion of the ulnar artery and various fractures.

A bystander was struck on the right foot, with the amputation of three toes and injury to the remaining two. A spectator struck by the propellor of a PPG sustained severe facial injuries and another sustained minor injuries to the eye area.

Another bystander suffered amputation of the last three fingers of his left hand after being struck by a paramotor propellor.

A bystander was hit during a hard landing, suffering a minor injury to the forearm.

A power-paraglider pilot was struck by a PPG which was taking off, with the loss of a tooth, and two passengers of a hot air balloon hit during flight by a PPG sustained unknown but minor injuries, as did a power paraglider pilot hit by another PPG.

Discussion

In our study, the weather conditions were a main or contributing cause of accidents in 10,1% of cases: weather conditions alone were the cause in 5.7% of cases, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than that reported in paragliding by Zeller [8], who cite adverse weather conditions as a cause in accident, or be the direct cause of injuries.

Our study data showed that the majority of accidents occurred during takeoff (32.9%, or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase of the flight is landing [3,8].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than with a P, limiting the possibility of adopting emergency manoeuvres and making use of an emergency parachute impossible.

The use of a engine can be the direct cause of accidents distinctive to PPG: the two causes listed as “fuel exhaustion” and “mechanical failure: power-plant/propeller” were responsible for 14% of accidents.

The engine may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant vary between 20 and 40 kg. In the case of collision, both of these factors synergise to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to 22.5kW; engine thrust is highest during takeoff: the phase of flight when PPG accidents occur most frequently.

In certain reports it is explicitly mentioned that it was precisely the energy supplied to the engine which rendered the impact fatal.

Various reports also describe that pilot errors had been to some extent determined by a state of mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG: the position of the crew and the centrifugal acceleration (increased by the thrust of the engine) hinder blood supply to the brain, with a high risk of suffering blackouts - or in any case a momentary state of mental confusion-at a time fatal) case of near-drowning. It is therefore inadvisable to fly a paramotor over or near water; it is essential that pilots, wishing to do so, adopt the use of self-inflating and specially designed safety systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine [3, 8-15] while in PPG the upper limbs are more frequently affected, while spinal injuries are less frequently involved.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew due to the thrust of the engine and the weight of the equipment.

The engine is undoubtedly the factor which distinguishes PPG from paragliding in terms of injury type; contact with the propeller caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands (Fig. 2), wrists, forearms, arms and shoulders, as well as all eleven fractures with loss of fingers cited in this study. Contact with incandescent engine parts was the cause of four cases of burnings to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burnings were the result of actual fires caused by combustion of the engine fuel. In another case, electrical burnings to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in P also, while burnings resulting from engine fuel combustion or contact with the engine are limited to PPG.

Indeed PPG is widely believed to be safer than paragliding, and fatal events considered to be rarer than in paragliding[1], in our study, 6% of accidents were fatal (fatal accidents/ total number of accidents: 23/383).

This figure is not lower than the values cited in literature for paragliding and hang-gliding (table 10) and is in any case comparable with the 6.1% of fatal paragliding accidents reported by Schulze (2002)[16] in a study very similar to ours, since it was conducted using the data from incident reports.

Considering the differences between PPG and paragliding future studies of this sport and related injuries should be conducted separately from paragliding, in separate case studies.

Certain types of safety clothing and equipment can significantly reduce various risks specific to this

The safety ring makes it difficult to an open human hand from going into the prop at full rated thrust and adds very little in terms of expense, and weight to the paramotor. Its use should be made obligatory, given that these injuries are often severe, in some cases involving amputation of the fingers. Given the extreme danger of water immersion, it is essential that pilots equip themselves with an Agama when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the engine is vital, given that its malfunctioning is a major cause of accidents.

This study has some limitations.

First of all since there is no way of finding exactly how many people knew the existance of the database, the effect of of under-reporting bias due to the voluntary nature of our data collection, can be hardly estimated .

In addition, beeing the injury reporting online, only powered paragliders with access to the Internet were able to participate. For this reason, even though most people use the Internet, selection bias cannot be excluded at all.

Finally the lack of a specific question about the kind of injury in the form, might have led to the loss of some data even if in almost all the cases it was possible to obtain detailed informations on the type of injuries by a careful reading of the narrative section of the reports.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in P and in hang-gliding[9,10,16,17](table 8).

Table 8. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	Study	No. fatalities	No. participants	% Fatal events
Paragliding	Krüger-Franke et al. (1991)[9].	2	218	0.91%

reports. Further studies will be useful to confirm the data from this study: we can nevertheless assert that safety equipment such as protective gloves, a safety ring and an auto-inflating flotation devices, in addition to periodical checks of the engine can reduce certain risks specific to this sport.

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Competing interests None.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Keywords

Extreme Sports, Sporting injuries, Protective clothing, Motor sports, Injury prevention

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding is a clearly distinct sport from paragliding, mainly because of the use of an engine. We supposed that the differences between these two sports result in different types of injuries.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1).

Outcome: to identify he most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs (44.5%) followed by the lower limbs (32 %), the back (9,8,%), the head (7%), the pelvis (3,1), the chest (2,7%) and the abdomen (0,7%) ($p < 0{,}001$).

The engine caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help to prevent the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in future this sport should be studied using studies and case reports distinct from those of paragliding.

Strengths and limitations of this study

This is the first study in literature on powered-paragliding.

We analyzed a large amount of data (384 incident reports) collected from 1995 to 2012.

means of long lines. It is a completely different sport from paragliding because the equipment used includes a engine worn on the back and held in place by a harness (Fig. 1).

In contrast to paragliding, which is practised over hilly or mountain areas, because it requires a descent in order to take off, the PPG can take off from level ground thanks to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG: both require the pilot to keeps the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much so that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised only in the United States, by just 3000 persons [1].

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. A knowledge of accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine to provide an insight into the types of conduct, protective clothing and safety systems to adopt to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies of this sport in medical literature except from a case we have previously reported [2]: in a recent literature review [3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that the accident and injury types differ greatly between the two sports as a result.

The aim of this study is to clarify the dynamics of paramotoring accidents, the conditions in which these occur, the type of injuries sustained, and to highlight any differences with respect to paragliding.

2012 (the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but since USPPA is very popular among powered paragliders worldwide, also accidents from other countries were reported.

The forms submitted had been completed by the pilot involved, a witness who had seen the accident, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields and consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information, including demographic information and details of the pilot's PPG experience;

3-Details of the accident, including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extended description of the event and its consequences.

In the form, a specific question on the quality of injuries was missing, but a careful reading of the narrative section allowed to obtain these informations from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score: a 7-point system (table 1) developed to assess the severity of injuries and diseases sustained or developed during aviation accidents. Based on the available data, nevertheless, it was not possible to distinguish between classes V and VI in all cases.

Table 1: NACA Score

NACA I	intervention necessary.	E.g. slight abrasion.
NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical investigation, but usually no emergency medical measures necessary.	E.g. fracture of a finger bone, moderate cuts, dehydration.
NACA III	Moderate to heavy but not life-threatening disorder. Frequently emergency medical measures on the site	E.g. femur fracture, milder stroke, smoke inhalation
NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	E.g. vertebral injury with neurological deficit, severe asthma attack; drug poisoning
NACA V	Acute vital (life threatening) danger	E.g. third grade skull or brain trauma, severe heart attack, significant opioid poisoning
NACA VI	Breath and/or cycle stop and/or reanimation	---
NACA VII	Death	---

Both categories cover conditions posing an immediate threat to life and requiring immediate emergency medical assistance: therefore we decided to consider them as a single category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and divided these into 3 classes based on the severity of the injuries:

1-minor (NACA I, II), usually not requiring emergency medical measures

2-major (NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal (NACA VII).

We associated the incidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

The pilots involved in power paragliding accidents were aged between 24 and 72 (average age=

excluded.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1). Only three incidents involved a female pilot.

Pilot injuries were classified according to NACA category (table 2): 23 incidents were fatal.

Table 2.NACA Score of PPG accidents in this study

NACA Category	Pilots	%
0	194	50,6
I	59	15,4
II	48	12,5
III	43	11,2
IV	11	2,9
V + VI	5	1,3
VII	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place (table 3), the primary cause (table 4) and the type of accident (table 5).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25,5% PPG2, 13,5% PPG1, 15,1% PPG3, 9,1% Instructor, 12,8% None, 11,7% Not applicable, 6% Unknown, 1,8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating (chi-square, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70,5% flat terrain, 11,4% not applicable, 8,8% hilly terrain, 2,6% water, 2,6 % mountainous terrain, 2,6% unknown data, 1,3% other.

Table 3. Phase of Flight

Phase of Flight	Count	%

landing)		
Not Applicable/Other	56	14,6%

Table 4. Primary cause of accidents

Primary cause	Tot.	%
Pilot Errors (only)	205	53,5
Mechanical Failure (including fuel exhaustion)	67	17,5
Pilot Error & Weather	17	4,4
Pilot Error & Mechanical Failure	17	4,4
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5,7
Not Applicable/unknown	24	4,4
Other (including wake Tight takeoff/LZ Area)	31	1,8

Table 5. Type of accidents

Type	Tot.	%
Collision with Terrain/Obstruction on Ground	76	19,8
Powerplant Equipment Malfunction	58	15,1
Body contact with spinning prop	43	11,2
Hard Landing	40	10,4
Fall	37	9,7
Wing Malfunction or Deflation	35	9,1
Other	29	7,5
Handling	20	5,2
Line Tangle/Damage	15	3,9
Collision with other Aircraft/Ultralight	14	3,6
Water Immersion	10	2,6

To identify the most affected body areas and therefore most critical areas for the development of protective clothing, we calculated the number of injuries sustained in each body area (table 6). On a total of 256 injuries, the most affected body areas were the upper limbs (44.5%) followed by the lower limbs (32 %) and the back (9,7 %).

Table 6. Distribution of the injuries sustained in the different body regions in power paragliding as emerged from this study.(chi -square , p < 0,001).

Body region	Body area	No. Cases	Types of Injury (number of cases)	Tot	% of all injuries
Head	Head	7	Concussions(3), unknown(2), contusions(1), open wounds(1)	18	7%
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds (1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3),tendon injuries (3),dislocations (2),lacerations (2),unknown (2),abrasions (1),burnings (1),contusions (1),muscle strains (1), sprains (1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11 with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9,7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1), other(1)	8	3.1%
Lower Limb	Thigh	13	Fractures(4), contusions(2), lacerations(2), open wounds(2), abrasion (1), burnings(1), unknown(1)	82	32%

			ligament ruptures(1), other(1)		
	Foot	11	Fracture(3), unknown(3), contusions(2), other(2), lacerations(1)		

Of the twenty-three fatal accidents, five were the result of an involuntary landing in water: one autopsy revealed the cause of drowning to be head injury with haemorrhage and loss of consciousness.

Another two accidents were fatal due to cerebral spine fractures with spinal cord damage.

In four cases, death was caused by severe head trauma. In all remaining cases, death was the result of high-energy multi-trauma, although the reports do not allow us to identify the precise injuries responsible for death, even if this were possible.

Most of the injuries were minor ones (NACA I-II) followed by major ones(NACA III-VI) and fatals ones (NACA VII).

No significant difference in the distribution of fatal, major and minor injuries among the three main phases of flight (takeoff including inflation and runup, cruise and landing including approach) was found.

With regard to the relationship between accident dynamic and accident severity, body contact with spinning prop and wing malfunction/deflation prevalently caused major injuries (NACA III-VI), representing respectively 55,6% and 56,2% of the injuries causes.

Accidents due to water immersion were prevalently fatal (71,4%).

The other dynamics of injuries cause mainly minor injuries (NACAI-II).

The statistical correlation between injury severity and type of incident (chi-square, $p < 0.001$; confidence 95%) is shown in Table. 7.

Table 7. Severity of Injuries by Type of Incident

Type of incident	**Minor (%)**	**Major (%)**	**Fatal (%)**
Collision with Terrain/Obstruction on Ground	62,5	18,8	18,8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44,4	55,6	0
Hard Landing	74,1	22,2	3,7
Fall	54,5	40,9	4,5

Collision with other Aircraft/Ultralight	40	40	20
Water Immersion	14,3	14,3	71,4
All Types of Incident	**56,6**	**31,2**	**12,2**

The correlation between accident severity and pilot rating is scarcely significant (chi-square, p=0.044; confidence 95%).

The data on the collateral damage from the various accidents reveals that in addition to the 383 pilots directly involved, seven bystanders and sixteen pilots of other aircraft involved in collisions were also injured, for a total of 406 persons. The data was insufficient to precisely classify the severity of the injuries suffered by these persons. No injuries were sustained in thirteen cases.

A paramotor instructor was struck on the right hand by a pilot's propellor, with lesion of the ulnar artery and various fractures.

A bystander was struck on the right foot, with the amputation of three toes and injury to the remaining two. A spectator struck by the propellor of a PPG sustained severe facial injuries and another sustained minor injuries to the eye area.

Another bystander suffered amputation of the last three fingers of his left hand after being struck by a paramotor propellor.

A bystander was hit during a hard landing, suffering a minor injury to the forearm.

A power-paraglider pilot was struck by a PPG which was taking off, with the loss of a tooth, and two passengers of a hot air balloon hit during flight by a PPG sustained unknown but minor injuries, as did a power paraglider pilot hit by another PPG.

Discussion

In our study, the weather conditions were a main or contributing cause of accidents in 10,1% of cases: weather conditions alone were the cause in 5.7% of cases, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than that reported in paragliding by Zeller [8], who cite adverse weather conditions as a cause in 19% of paragliding accidents.

This can be explained by the fact that engine makes it possible to fly frequently and in a much

43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase of the flight is landing [3,8].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than with a P, limiting the possibility of adopting emergency manoeuvres and making use of an emergency parachute impossible.

The use of a engine can be the direct cause of accidents distinctive to PPG: the two causes listed as “fuel exhaustion” and “mechanical failure: power-plant/propeller” were responsible for 14% of accidents.

The engine may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant vary between 20 and 40 kg. In the case of collision, both of these factors synergise to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to 22.5kW; engine thrust is highest during takeoff: the phase of flight when PPG accidents occur most frequently.

In certain reports it is explicitly mentioned that it was precisely the energy supplied to the engine which rendered the impact fatal.

Various reports also describe that pilot errors had been to some extent determined by a state of mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration (increased by the thrust of the engine) hinder blood supply to the brain, with a high risk of suffering blackouts - or in any case a momentary state of mental confusion-at a time when the maximum level of attention is required.

In the case of immersion in water, the weight of the engine tends to drag the pilot rapidly under the systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine [3, 8-15] while in PPG the upper limbs are more frequently affected, while spinal injuries are less frequently involved.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew due to the thrust of the engine and the weight of the equipment.

The engine is undoubtedly the factor which distinguishes PPG from paragliding in terms of injury type; contact with the propeller caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands (Fig. 2), wrists, forearms, arms and shoulders, as well as all eleven fractures with loss of fingers cited in this study. Contact with incandescent engine parts was the cause of four cases of burnings to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burnings were the result of actual fires caused by combustion of the engine fuel. In another case, electrical burnings to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in P also, while burnings resulting from engine fuel combustion or contact with the engine are limited to PPG.

Indeed PPG is widely believed to be safer than paragliding, and fatal events considered to be rarer than in paragliding[1], in our study, 6% of accidents were fatal (fatal accidents/ total number of accidents: 23/383).

This figure is not lower than the values cited in literature for paragliding and hang-gliding (table 10) and is in any case comparable with the 6.1% of fatal paragliding accidents reported by Schulze (2002)[16] in a study very similar to ours, since it was conducted using the data from incident reports.

Considering the differences between PPG and paragliding future studies of this sport and related injuries should be conducted separately from paragliding, in separate case studies.

Certain types of safety clothing and equipment can significantly reduce various risks specific to this sport. The use of protective gloves in particular can protect against hand injuries caused by contact with the spinning prop.

obligatory, given that these injuries are often severe, in some cases involving amputation of the fingers. Given the extreme danger of water immersion, it is essential that pilots equip themselves with an Agama when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the engine is vital, given that its malfunctioning is a major cause of accidents.

This study has some limitations.

First of all since there is no way of finding exactly how many people knew the existance of the database, the effect of of under-reporting bias due to the voluntary nature of our data collection, can be hardly estimated .

In addition, beeing the injury reporting online, only powered paragliders with access to the Internet were able to participate. For this reason, even though most people use the Internet, selection bias cannot be excluded at all.

Finally the lack of a specific question about the kind of injury in the form, might have led to the loss of some data even if in almost all the cases it was possible to obtain detailed informations on the type of injuries by a careful reading of the narrative section of the reports.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in P and in hang-gliding[9,10,16,17](table 8).

Table 8. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	Study	No. fatalities	No. participants	% Fatal events
Paragliding	Krüger-Franke et al. (1991)[9].	2	218	0.91%
Paragliding	Schulze et al. (2002)[16].	25	409	6.10%
Paragliding	Fashing et al. (1997)[10]	0	70	0.00%

Contributorship Statement

The study was conceived by Francesco Feletti and Jeff Goin.

Jeff Goin collected data.

Francesco Feletti carried out statistical analyses and wrote the draft of the manuscript. All authors contributed to critical revisions of the manuscript and approved the final version.

Data sharing statement No additional data are available.

Competing interests None.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Figure 1: Paramotor in flight
134x101mm (300 x 300 DPI)

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

90x67mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
Yes		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **Yes**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **Yes**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **Yes**	4	Present key elements of study design early in the paper
Setting **Yes**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **Yes**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **Yes**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **Yes**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias **Yes**	9	Describe any efforts to address potential sources of bias
Study size **Yes**	10	Explain how the study size was arrived at
Quantitative variables **Yes**	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **Yes**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **Yes**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **Yes**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **Yes**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **Yes**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses **Yes**	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results **Yes**	18	Summarise key results with reference to study objectives
Limitations **Yes**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **Yes**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **Yes**	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding **Yes**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Accidents and injuries related to powered paragliding: a cross sectional study

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding is a clearly distinct sport from paragliding, mainly because of the use of an engine. We presumed that the differences between these two sports have as a result different types of injuries.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1).

Outcome: to identify the most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs (44.5%) followed by the lower limbs (32 %), the back (9,8,%), the head (7%), the pelvis (3,1), the chest (2,7%) and the abdomen (0,7%) ($p < 0{,}001$).

The engine caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help preventing the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in the future this sport should be analyzed separately from paragliding.

Strengths and limitations of this study

This is the first study in literature on powered-paragliding.

We analyzed a large amount of data (384 incident reports) collected from 1995 to 2012.

similar to that of paragliding, the sport from which it derives, under which the crew is suspended by means of long lines. It is a completely different sport from paragliding because the equipment used includes an engine worn on the back and held in place by a harness(Fig. 1).

In contrast to paragliding, which is practised over hilly or mountaineous areas, because it requires a descent in order to take off, the PPG can take off from level ground thank to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG: both require the pilot to keep the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised only in the United States, by just 3000 people [1].

It seems to be a prevalently male sport, judging from the fact that in 2013 female members of the association has been 2,6%.

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. Knowing the accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine in order to provide an insight into the types of conduct, protective clothing and safety systems which should be adopted to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies on this sport in medical literature except from a case we had previously reported[2]: in a recent literature review[3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that the accident and injury types differ greatly between the two sports as a result.

the US Powered Paragliding Association(USPPA) collected using a specific form published on its website[4].

The collection of the data started in 1995: we decided to use all the data available between 1995 and 2012(the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but since USPPA is very popular among powered paragliders worldwide, accidents from other countries were also reported.

The forms submitted had been completed by the pilot involved, by a witness, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields.

The form consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information: including demographic information and details of the pilot's PPG experience;

3-Details on the accident: including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extensive description of the event and its consequences.

The form lacked a specific question about the nature of the injuries but a careful reading of the narrative section, allowed to obtain these information from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The reading of the narrative section was carried out by only one researcher.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score:

category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and we divided these into 3 classes based on the severity of the injuries:

1-minor (NACA I, II), usually not requiring emergency medical measures

2-major (NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal (NACA VII).

We associated the accidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

At the starting date of the present study, 384 incident reports were available.

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The pilots involved in powered paragliding accidents were aged between 24 and 72(average age= 44.5, median= 48, SD= 9.54).

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia (Java)(1), Europe (8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1). Only three incidents involved a female pilot.

Pilot injuries were classified according to NACA category(table 1).

Table 1.NACA Score of PPG accidents in this study

Category	Description	Pilots	%
NACA 0	No injury or disease.	194	50,6
NACA I	Slight injury or illness. No acute medical intervention necessary.	59	15,4
NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical	48	12,5

NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	11	2,9
NACA V	Acute vital (life threatening) danger	5	1,3
NACA VI	Breath and/or cycle stop and/or reanimation		
NACA VII	Death	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place(table 2), the primary cause(table 3) and the type of accident(table 4).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25,5% PPG2 (pilots who have an experience of 40 or more flights[4]), 13,5% PPG1(experience of 2 flights or more), 15,1% PPG3(experience of 200 or more flights), 9,1% Instructor, 12,8% None, 11,7% Not applicable, 6% Unknown, 1,8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating(*chi-square*, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70,5% flat terrain, 11,4% not applicable, 8,8% hilly terrain, 2,6% water, 2,6 % mountainous terrain, 2,6% unknown data, 1,3% other.

Table 2. Phase of Flight

Phase of Flight	**Count**	**%**
Takeoff (including inflation and runup)	**165**	**43%**
Cruise	**107**	**27,9%**
Landing (including approach and after landing)	**55**	**14,3%**
Not Available/Other	**56**	**14,6%**

exhaustion)		
Pilot Error & Weather	17	4,4
Pilot Error & Mechanical Failure	17	4,4
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5,7
Not Applicable/unknown	24	4,4
Other (including wake Tight takeoff/LZ Area)	31	1,8

Table 4. Type of Accidents

Type	Tot.	%
Collision with Terrain/Obstruction on Ground	76	19,8
Powerplant Equipment Malfunction	58	15,1
Body contact with spinning prop	43	11,2
Hard Landing	40	10,4
Fall	37	9,7
Wing Malfunction or Deflation	35	9,1
Other	29	7,5
Handling	20	5,2
Line Tangle/Damage	15	3,9
Collision with other Aircraft/Ultralight	14	3,6
Water Immersion	10	2,6
Other/Not Applicable	35	1,5

To identify the most affected body areas and therefore most critical areas for the development of protective clothing, we calculated the number of injuries sustained in each body area (table 5). On a total of 256 injuries, the most affected body areas were the upper limbs(44.5%) followed by the lower limbs(32 %) and the back(9,7 %).

Table 5. Distribution of the Injuries sustained in the different Body Regions in Powered

			open wounds(1)		
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds (1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3),tendon injuries (3),dislocations (2),lacerations (2),unknown (2),abrasions (1),burnings (1),contusions (1),muscle strains (1), sprains (1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11 with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9,7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1), other(1)	8	3.1%
Lower Limb	Thigh	13	Fractures(4), contusions(2), lacerations(2), open wounds(2), abrasion (1), burnings(1), unknown(1)	82	32%
	Knee	19	Contusions(4), sprains(4), lacerations(2), ligament ruptures(2), unknown(2), abrasions(1), dislocations(1), meniscus and ligament tears(1), muscle strains(1), others(1)		
	Calf	17	Fractures(7), burnings(2), contusions(2), lacerations(2), unknown(2), wounds(2)		
	Ankle	22	Sprains(8), fractures(5), contusions(3), unknown(3), dislocations(1), ligament ruptures(1), other(1)		
	Foot	11	Fracture(3), unknown(3), contusions(2), other(2), lacerations(1)		

Of the twenty-three fatal accidents, five were the result of an involuntary landing on water and

Most of the injuries were minor ones(NACA I-II) followed by major ones(NACA III-VI) and fatals ones(NACA VII).

No significant difference in the distribution of fatal, major and minor injuries among the three main phases of flight(takeoff including inflation and runup, cruise and landing including approach) was found.

With regard to the relationship between accident dynamic and accident severity,

Accidents due to body contact with spinning prop and wing malfunction/deflation caused prevalently major injuries (NACA III-VI): 55,6% and 56,2% respectively.

Accidents due to water immersion were prevalently fatal (71,4%).

The other dynamics of injuries cause mainly minor injuries(NACAI-II).

A statistical correlation between injury severity and type of accident was found**(*chi-square*, p < 0.021; confidence 95%); severity of injuries by type of accident is shown in Table 6.**

Table 6. Severity of Injuries by Type of Accident

Type of Accident	Minor (%)	Major (%)	Fatal (%)
Collision with Terrain/Obstruction on Ground	62,5	18,8	18,8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44,4	55,6	0
Hard Landing	74,1	22,2	3,7
Fall	54,5	40,9	4,5
Wing Malfunction or Deflation	31,2	56,2	12,5
Other	80	0	20
Handling	53,8	23,1	23,1
Line Tangle/Damage	100	0	0
Collision with other Aircraft/Ultralight	40	40	20
Water Immersion	14,3	14,3	71,4
All Types of Accident	**56,6**	**31,2**	**12,2**

The correlation between accident severity and pilot rating is scarcely significant*(chi-square*,

Discussion

In our study, the weather conditions were a main or contributing cause of 10,1% of accidents: weather conditions alone were the cause of 5.7% of accidents, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than that reported in paragliding by Zeller[9], who mentions adverse weather conditions as a cause in 19% of paragliding accidents.

This can be explained by the fact that engine allows to fly frequently and in a much wider variety of weather conditions, so pilots are less likely to risk flying in extreme and hazardous conditions.

Nevertheless, our study clearly shows that the use of an engine influences the accident dynamics.

It can itself be the cause of accidents, it can be an important aggravating factor in the event of an accident or it can also be the direct cause of injuries.

Our study data showed that the majority of accidents occurred during takeoff(32.9%, or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase is landing[3,9].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than it does with a P, limiting the possibility of adopting emergency manoeuvres and making the use of an emergency parachute impossible.

The use of an engine can be the direct cause of accidents distinctive to PPG: the two causes listed as “fuel exhaustion” and “mechanical failure: power-plant/propeller” were responsible for 14% of accidents.

The engine may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant, vary between 20 and 40 kg. In the case of collision, both of these factors synergize to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration (increased by the thrust of the engine) may reduce blood supply to the brain, and could cause momentary state of mental confusion or even blackouts at a time when the maximum level of attention is required[10].

In the case of immersion in water, the weight of the engine can drag the pilot rapidly under the surface, without giving him time to free himself from the equipment, making this type of accident particularly feared among paramotor pilots. In our study, this dynamic was responsible for 21.7 % of fatal accidents(71.4% of accidents involving water immersion were fatal) and a serious (non-fatal) case of near-drowning. It is therefore inadvisable to fly a paramotor over or near water; it is essential that pilots, wishing to do so, adopt the use of self-inflating and specially designed safety systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO_2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine [3, 9-17] while in PPG the upper limbs are more frequently affected and spinal injuries are less common.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew. This is due to the thrust of the engine and the weight of the equipment.

The engine is undoubtedly the factor which distinguishes PPG from paragliding in terms of injury type; contact with the propeller caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands (Fig. 2), wrists, forearms, arms and shoulders, as well as all eleven fractures with loss of fingers cited in this study. Contact with very hot engine parts was the cause of four cases of burnings to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burnings were the result of actual fires caused by combustion of the engine fuel. In another case, electrical burnings to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in paragliding too, while burnings resulting from engine fuel combustion or contact with the engine are specific to PPG.

Indeed PPG is widely believed to be safer than paragliding, and fatal events considered to be

Table 7. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	Study	No. fatalities	No. participants	% Fatal events
Paragliding	Krüger-Franke et al. (1991)[11].	2	218	0.91%
Paragliding	Schulze et al. (2002)[18].	25	409	6.10%
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Hang-gliding	Foray et al (1991)[20].	7	200	3.50%

Considering the differences between PPG and paragliding further research on this sport and related injuries should be conducted separately from paragliding, in separate studies.

The results of this study suggest that further investigation should consider if the use of certain types of safety clothing and equipment can significantly reduce various risks specific to this sport.

The effectiveness of protective gloves to protect against hand injuries caused by contact with the spinning prop should be evalued in future studies.

Since many prop strike injuries have been higher on the upper limb where gloves would not be effective, an even better solution could be to add the so called "safety ring" to the engine cage. The safety ring is an aluminum ring that mounts just forward the radial arms with the same radius as the prop. The safety ring is designed to make it difficult for an open human hand to reach the prop at full rated thrust and it adds very little in terms of expense, and weight to the equipment.

Further studies should evaluate its effectiveness and its use could eventually be made obligatory, given that these injuries are often severe, in some cases involving amputation of the fingers. Given the extreme danger caused by water immersion, it might be useful that pilots provide themselves with an auto-inflating flotation device when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the engine is vital, given that its malfunctioning could represent a cause of major injuries.

This study has some limitations.

First of all since there is no way of finding out exactly how many people knew about the existance of the database, the effect of under-reporting bias, due to the voluntary nature of our data to the loss of some data even if in almost all the cases it was possible to obtain detailed information on the type of injuries by a careful reading of the narrative section of the reports.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in paragliding and in hang-gliding[11, 12, 18, 19, 20](table 7).

For these reasons, PPG should be analysed separately from paragliding in distinct studies.

Further research will be useful to confirm the data of this study, to investigate the role of safety equipment such as protective gloves, safety ring and auto-inflating flotation devices and to evaluate the effectiveness of periodical checks of the engine, to reduce certain risks specific to this sport.

Contributorship Statement

The study was conceived by Francesco Feletti and Jeff Goin.

Jeff Goin collected data.

Francesco Feletti carried out statistical analysis and wrote the draft of the manuscript. All authors contributed to critical revisions of the manuscript and approved the final version.

Data sharing statement: No additional data available.

Competing interests: None.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Keywords
Extreme Sports, Paragliding, Sporting injuries, Adventure Sports,

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding is a clearly distinct sport from paragliding, mainly because of the use of an engine. We presumed that the differences between these two sports have as a result different types of injuries.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada (8), Mexico (5), Panama (1), China (1), Japan (1), Malaysia (1), Indonesia (Java)(1), Europe (8): of which Spain (1), Belgium (1), United Kingdom (3), Italy (1), Romania (1), Unknown (1).

Outcome: to identify the most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs (44.5%) followed by the lower limbs (32 %), the back (9,8,%), the head (7%), the pelvis (3,1), the chest (2,7%) and the abdomen (0,7%) ($p < 0,001$).

The engine caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help preventing the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in the future this sport should be analyzed separately from paragliding.

Strengths and limitations of this study

This is the first study in literature on powered-paragliding.

We analyzed a large amount of data (384 incident reports) collected from 1995 to 2012.

similar to that of paragliding, the sport from which it derives, under which the crew is suspended by means of long lines. It is a completely different sport from paragliding because the equipment used includes an engine worn on the back and held in place by a harness(Fig. 1).

In contrast to paragliding, which is practised over hilly or mountaineous areas, because it requires a descent in order to take off, the PPG can take off from level ground thank to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG: both require the pilot to keep the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised only in the United States, by just 3000 people [1].

It seems to be a prevalently male sport, judging from the fact that in 2013 female members of the association has been 2,6%.

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. Knowing the accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine in order to provide an insight into the types of conduct, protective clothing and safety systems which should be adopted to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies on this sport in medical literature except from a case we had previously reported[2]: in a recent literature review[3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that the accident and injury types differ greatly between the two sports as a result.

the US Powered Paragliding Association(USPPA) collected using a specific form published on its website[4].

The collection of the data started in 1995: we decided to use all the data available between 1995 and 2012(the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but since USPPA is very popular among powered paragliders worldwide, accidents from other countries were also reported.

The forms submitted had been completed by the pilot involved, by a witness, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields.

The form consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information: including demographic information and details of the pilot's PPG experience;

3-Details on the accident: including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extensive description of the event and its consequences.

The form lacked a specific question about the nature of the injuries but a careful reading of the narrative section, allowed to obtain these information from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The reading of the narrative section was carried out by only one researcher.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score:

category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and we divided these into 3 classes based on the severity of the injuries:

1-minor (NACA I, II), usually not requiring emergency medical measures

2-major (NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal (NACA VII).

We associated the accidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

At the starting date of the present study, 384 incident reports were available.

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The pilots involved in powered paragliding accidents were aged between 24 and 72(average age= 44.5, median= 48, SD= 9.54).

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia (Java)(1), Europe (8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1). Only three incidents involved a female pilot.

Pilot injuries were classified according to NACA category(table 1).

Table 1.NACA Score of PPG accidents in this study

Category	Description	Pilots	%
NACA 0	No injury or disease.	194	50,6
NACA I	Slight injury or illness. No acute medical intervention necessary.	59	15,4
NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical	48	12,5

NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	11	2,9
NACA V	Acute vital (life threatening) danger	5	1,3
NACA VI	Breath and/or cycle stop and/or reanimation		
NACA VII	Death	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place(table 2), the primary cause(table 3) and the type of accident(table 4).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25,5% PPG2 (pilots who have an experience of 40 or more flights[4]), 13,5% PPG1(experience of 2 flights or more), 15,1% PPG3(experience of 200 or more flights), 9,1% Instructor, 12,8% None, 11,7% Not applicable, 6% Unknown, 1,8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating(*chi-square*, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70,5% flat terrain, 11,4% not applicable, 8,8% hilly terrain, 2,6% water, 2,6 % mountainous terrain, 2,6% unknown data, 1,3% other.

Table 2. Phase of Flight

Phase of Flight	Count	%
Takeoff (including inflation and runup)	165	43%
Cruise	107	27,9%
Landing (including approach and after landing)	55	14,3%
Not Available/Other	56	14,6%

exhaustion)		
Pilot Error & Weather	17	4,4
Pilot Error & Mechanical Failure	17	4,4
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5,7
Not Applicable/unknown	24	4,4
Other (including wake Tight takeoff/LZ Area)	31	1,8

Table 4. Type of Accidents

Type	**Tot.**	**%**
Collision with Terrain/Obstruction on Ground	76	19,8
Powerplant Equipment Malfunction	58	15,1
Body contact with spinning prop	43	11,2
Hard Landing	40	10,4
Fall	37	9,7
Wing Malfunction or Deflation	35	9,1
Other	29	7,5
Handling	20	5,2
Line Tangle/Damage	15	3,9
Collision with other Aircraft/Ultralight	14	3,6
Water Immersion	10	2,6
Other/Not Applicable	35	1,5

To identify the most affected body areas and therefore most critical areas for the development of protective clothing, we calculated the number of injuries sustained in each body area (table 5). On a total of 256 injuries, the most affected body areas were the upper limbs(44.5%) followed by the lower limbs(32 %) and the back(9,7 %).

Table 5. Distribution of the Injuries sustained in the different Body Regions in Powered

			open wounds(1)		
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds (1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3),tendon injuries (3),dislocations (2),lacerations (2),unknown (2),abrasions (1),burnings (1),contusions (1),muscle strains (1), sprains (1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11 with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9,7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1), other(1)	8	3.1%
Lower Limb	Thigh	13	Fractures(4), contusions(2), lacerations(2), open wounds(2), abrasion (1), burnings(1), unknown(1)	82	32%
	Knee	19	Contusions(4), sprains(4), lacerations(2), ligament ruptures(2), unknown(2), abrasions(1), dislocations(1), meniscus and ligament tears(1), muscle strains(1), others(1)		
	Calf	17	Fractures(7), burnings(2), contusions(2), lacerations(2), unknown(2), wounds(2)		
	Ankle	22	Sprains(8), fractures(5), contusions(3), unknown(3), dislocations(1), ligament ruptures(1), other(1)		
	Foot	11	Fracture(3), unknown(3), contusions(2), other(2), lacerations(1)		

Of the twenty-three fatal accidents, five were the result of an involuntary landing on water and

Most of the injuries were minor ones(NACA I-II) followed by major ones(NACA III-VI) and fatals ones(NACA VII).

No significant difference in the distribution of fatal, major and minor injuries among the three main phases of flight(takeoff including inflation and runup, cruise and landing including approach) was found.

With regard to the relationship between accident dynamic and accident severity,

Accidents due to body contact with spinning prop and wing malfunction/deflation caused prevalently major injuries (NACA III-VI): 55,6% and 56,2% respectively.

Accidents due to water immersion were prevalently fatal (71,4%).

The other dynamics of injuries cause mainly minor injuries(NACAI-II).

A statistical correlation between injury severity and type of accident was found**(*chi-square*, p < 0.021; confidence 95%); severity of injuries by type of accident is shown in Table 6.**

Table 6. Severity of Injuries by Type of Accident

Type of Accident	**Minor (%)**	**Major (%)**	**Fatal (%)**
Collision with Terrain/Obstruction on Ground	62,5	18,8	18,8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44,4	55,6	0
Hard Landing	74,1	22,2	3,7
Fall	54,5	40,9	4,5
Wing Malfunction or Deflation	31,2	56,2	12,5
Other	80	0	20
Handling	53,8	23,1	23,1
Line Tangle/Damage	100	0	0
Collision with other Aircraft/Ultralight	40	40	20
Water Immersion	14,3	14,3	71,4
All Types of Accident	**56,6**	**31,2**	**12,2**

The correlation between accident severity and pilot rating is scarcely significant*(chi-square*,

Discussion

In our study, the weather conditions were a main or contributing cause of 10,1% of accidents: weather conditions alone were the cause of 5.7% of accidents, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than that reported in paragliding by Zeller[9], who mentions adverse weather conditions as a cause in 19% of paragliding accidents.

This can be explained by the fact that engine allows to fly frequently and in a much wider variety of weather conditions, so pilots are less likely to risk flying in extreme and hazardous conditions.

Nevertheless, our study clearly shows that the use of an engine influences the accident dynamics.

It can itself be the cause of accidents, it can be an important aggravating factor in the event of an accident or it can also be the direct cause of injuries.

Our study data showed that the majority of accidents occurred during takeoff(32.9%, or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase is landing[3,9].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than it does with a P, limiting the possibility of adopting emergency manoeuvres and making the use of an emergency parachute impossible.

The use of an engine can be the direct cause of accidents distinctive to PPG: the two causes listed as “fuel exhaustion” and “mechanical failure: power-plant/propeller” were responsible for 14% of accidents.

The engine may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant, vary between 20 and 40 kg. In the case of collision, both of these factors synergize to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration (increased by the thrust of the engine) may reduce blood supply to the brain, and could cause momentary state of mental confusion or even blackouts at a time when the maximum level of attention is required[10].

In the case of immersion in water, the weight of the engine can drag the pilot rapidly under the surface, without giving him time to free himself from the equipment, making this type of accident particularly feared among paramotor pilots. In our study, this dynamic was responsible for 21.7 % of fatal accidents(71.4% of accidents involving water immersion were fatal) and a serious (non-fatal) case of near-drowning. It is therefore inadvisable to fly a paramotor over or near water; it is essential that pilots, wishing to do so, adopt the use of self-inflating and specially designed safety systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine [3, 9-17] while in PPG the upper limbs are more frequently affected and spinal injuries are less common.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew. This is due to the thrust of the engine and the weight of the equipment.

The engine is undoubtedly the factor which distinguishes PPG from paragliding in terms of injury type; contact with the propeller caused 43 accidents (11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands (Fig. 2), wrists, forearms, arms and shoulders, as well as all eleven fractures with loss of fingers cited in this study. Contact with very hot engine parts was the cause of four cases of burnings to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burnings were the result of actual fires caused by combustion of the engine fuel. In another case, electrical burnings to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in paragliding too, while burnings resulting from engine fuel combustion or contact with the engine are specific to PPG.

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Considering the differences between PPG and paragliding further research on this sport and related injuries should be conducted separately from paragliding, in separate studies.

The results of this study suggest that further investigation should consider if the use of certain types of safety clothing and equipment can significantly reduce various risks specific to this sport.

The effectiveness of protective gloves to protect against hand injuries caused by contact with the spinning prop should be evalued in future studies.

Since many prop strike injuries have been higher on the upper limb where gloves would not be effective, an even better solution could be to add the so called "safety ring" to the engine cage. The safety ring is an aluminum ring that mounts just forward the radial arms with the same radius as the prop. The safety ring is designed to make it difficult for an open human hand to reach the prop at full rated thrust and it adds very little in terms of expense, and weight to the equipment.

Further studies should evaluate its effectiveness and its use could eventually be made obligatory, given that these injuries are often severe, in some cases involving amputation of the fingers. Given the extreme danger caused by water immersion, it might be useful that pilots provide themselves with an auto-inflating flotation device when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the engine is vital, given that its malfunctioning could represent a cause of major injuries.

This study has some limitations.

First of all since there is no way of finding out exactly how many people knew about the existance of the database, the effect of under-reporting bias, due to the voluntary nature of our data to the loss of some data even if in almost all the cases it was possible to obtain detailed information on the type of injuries by a careful reading of the narrative section of the reports.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in paragliding and in hang-gliding[11, 12, 18, 19, 20](table 7).

For these reasons, PPG should be analysed separately from paragliding in distinct studies.

Further research will be useful to confirm the data of this study, to investigate the role of safety equipment such as protective gloves, safety ring and auto-inflating flotation devices and to evaluate the effectiveness of periodical checks of the engine, to reduce certain risks specific to this sport.

Contributorship Statement

The study was conceived by Francesco Feletti and Jeff Goin.

Jeff Goin collected data.

Francesco Feletti carried out statistical analysis and wrote the draft of the manuscript. All authors contributed to critical revisions of the manuscript and approved the final version.

Data sharing statement: No additional data available.

Competing interests: None.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Figure 1: Paramotor in flight
134x101mm (300 x 300 DPI)

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

90x67mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **Yes**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **Yes**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **Yes**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **Yes**	4	Present key elements of study design early in the paper
Setting **Yes**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **Yes**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **Yes**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **Yes**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias **Yes**	9	Describe any efforts to address potential sources of bias
Study size **Yes**	10	Explain how the study size was arrived at
Quantitative variables **Yes**	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **Yes**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **Yes**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **Yes**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **Yes**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **Yes**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses **Yes**	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results **Yes**	18	Summarise key results with reference to study objectives
Limitations **Yes**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **Yes**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **Yes**	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding **Yes**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Accidents and injuries related to powered paragliding: a cross sectional study

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding and paragliding are two totally different sports, mainly because of the use of an engine in powered paragliding. As a consequence the pattern of injuries caused by each of these two sports may be different.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia(Java)(1), Europe(8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1).

Outcome: to identify the most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs(44.5%) followed by the lower limbs (32%), the back(9.8,%), the head(7%), the pelvis(3.1), the chest(2.7%) and the abdomen (0.7%) (p < 0,001).

The engine caused 43 accidents(11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help preventing the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in the future this sport should be analyzed separately from paragliding.

Strengths and limitations of this study

This is the first study in literature on powered-paragliding.

We analyzed a large amount of data(384 incident reports) collected from 1995 to 2012.

Powered paragliding or paramotor(PPG) is a sport in which the pilot flies by means of a wing similar to that of paragliding, the sport from which it derives, under which the crew is suspended by means of long lines. It is a sport on its own right: different because the equipment used includes an engine, worn on the back and held in place by a harness(Fig. 1).

In contrast to paragliding, which is practised over hilly or mountaineous areas, because it requires a descent in order to take off, the PPG can take off from level ground thank to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG they both require the pilot to keep the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised in the United States alone, by 3000 people[1].

It seems to be a prevalently male sport, judging from the fact that in 2013 the number of female members of the U.S. Powered Paragliding Association, represented only the 2.6% of the total members.

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. Knowing the accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine, in order to provide an insight into the types of conduct, protective clothing and safety systems, which should be adopted to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies on this sport in medical literature, except from a case we had previously reported[2]: in a recent literature review[3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that

We analysed the incident reports of the accidents occurred between 1995 and the end of 2012, that the US Powered Paragliding Association(USPPA) collected using a specific form published on its website[4].

The collection of the data started in 1995: we decided to use all the data available between 1995 and 2012(the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but, since USPPA is very popular among powered paragliders worldwide, accidents from other countries were also reported.

The forms submitted had been completed by the pilot involved, by a witness, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields.

The form consisted of five sections:

1-General information (date, time and place of the accident);

2-Pilot information: including demographic information and details of the pilot's PPG experience;

3-Details on the accident: including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extensive description of the event and its consequences.

The form lacked a specific question about the nature of the injuries but a careful reading of the narrative section, allowed to obtain these information from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The reading of the narrative section was carried out by only one researcher.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

immediate emergency medical assistance: therefore we decided to consider them as a single category.

We subsequently focused on the accidents resulting in injuries (disregarding those with a NACA score of 0), and we divided these into 3 classes based on the severity of the injuries:

1-minor(NACA I, II), usually not requiring emergency medical measures

2-major(NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal(NACA VII).

We associated the accidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

At the starting date of the present study, 384 incident reports were available.

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The pilots involved in powered paragliding accidents were aged between 24 and 72(average age= 44.5, median= 48, SD= 9.54).

The majority of the accidents described occurred in the US, while 26 occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia (Java)(1), Europe (8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1). Only three accidents involved a female pilot.

Pilot injuries were classified according to NACA category(table 1).

Table 1.NACA Score of PPG accidents in this study

Category	Description	Pilots	%
NACA 0	No injury or disease	194	50.6
NACA I	Slight injury or illness. No acute medical intervention necessary	59	15.4

	necessary		
NACA III	Moderate to heavy but not life-threatening disorder Frequently emergency medical measures on the site	43	11.2
NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	11	2.9
NACA V	Acute vital(life threatening) danger	5	1.3
NACA VI	Breath and/or cycle stop and/or reanimation		
NACA VII	Death	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place(table 2), the primary cause(table 3) and the type of accident(table 4).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25.5% PPG2 (pilots who have an experience of 40 or more flights[4]), 13.5% PPG1(experience of 2 flights or more), 15.1% PPG3(experience of 200 or more flights), 9.1% Instructor, 12.8% None, 11.7% Not applicable, 6% Unknown, 1.8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating(*chi-square*, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70.5% flat terrain, 11.4% not applicable, 8.8% hilly terrain, 2.6% water, 2.6 % mountainous terrain, 2.6% unknown data, 1.3% other.

Table 2. Phase of Flight

Phase of Flight	Count	%
Takeoff (including inflation and ...	165	43%

Not Available/Other	56	14.6%

Table 3. Primary Cause of Accidents

Primary cause	**Tot.**	**%**
Pilot Errors (only)	205	53.5
Mechanical Failure (including fuel exhaustion)	67	17.5
Pilot Error & Weather	17	4.4
Pilot Error & Mechanical Failure	17	4.4
Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5.7
Not Applicable/unknown	24	4.4
Other (including wake Tight takeoff/LZ Area)	31	1.8

Table 4. Type of Accidents

Type	**Tot.**	**%**
Collision with Terrain/Obstruction on Ground	76	19.8
Powerplant Equipment Malfunction	58	15.1
Body contact with spinning prop	43	11.2
Hard Landing	40	10.4
Fall	37	9.7
Wing Malfunction or Deflation	35	9.1
Other	29	7.5
Handling	20	5.2
Line Tangle/Damage	15	3.9
Collision with other Aircraft/Ultralight	14	3.6
Water Immersion	10	2.6
Other/Not Applicable	35	1.5

Paragliding as emerged from this study(*chi-square* , p < 0.001).

Body region	**Body area**	**No. Cases**	**Types of Injury (number of cases)**	**Tot**	**% of all injuries**
Head	Head	7	Concussions(3), unknown(2), contusions(1), open wounds(1)	18	7%
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds(1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3), tendon injuries (3), dislocations(2), lacerations(2), unknown(2), abrasions (1), burnings(1), contusions(1), muscle strains(1), sprains(1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9.7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1), other(1)	8	3.1%
Lower Limb	Thigh	13	Fractures(4), contusions(2), lacerations(2), open wounds(2), abrasion(1), burnings(1), unknown(1)	82	32%
	Knee	19	Contusions(4), sprains(4), lacerations(2), ligament ruptures(2), unknown(2), abrasions(1), dislocations(1), meniscus and ligament tears(1), muscle strains(1), others(1)		
	Calf	17	Fractures(7), burnings(2), contusions(2), lacerations(2), unknown(2), wounds(2)		
	Ankle	22	Sprains(8), fractures(5), contusions(3), unknown(3), dislocations(1),		

drawning: one autopsy revealed the cause of death to be drowning which was probably the consequence of the unconsciousness due to the head injury sustained.

Another two accidents were fatal due to cerebral spine fractures with spinal cord damage.

In four cases, death was caused by severe head trauma. In all remaining cases, death was the result of high-energy multi-trauma, although the reports do not allow us to identify the precise injuries responsible for death.

Most of the injuries were minor ones(NACA I-II) followed by major ones(NACA III-VI) and fatal ones(NACA VII).

No significant difference was found in the distribution of fatal, major and minor injuries among the three main phases of flight(takeoff including inflation and runup, cruise and landing including approach).

With regard to the relationship between accident dynamic and accident severity, accidents due to body contact with spinning prop and wing malfunction/deflation caused prevalently major injuries(NACA III-VI): 55.6% and 56.2% respectively.

Accidents due to water immersion were prevalently fatal(71.4%).

The other dynamics of injuries cause mainly minor injuries(NACAI-II).

A statistical correlation between injury severity and type of accident was found(chi-square, $p < 0.021$; confidence 95%); severity of injuries by type of accident is shown in Table 6.

Table 6. Severity of Injuries by Type of Accident

Type of Accident	Minor (%)	Major (%)	Fatal (%)
Collision with Terrain/Obstruction on Ground	62.5	18.8	18.8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44.4	55.6	0
Hard Landing	74.1	22.2	3.7
Fall	54.5	40.9	4.5
Wing Malfunction or Deflation	31.2	56.2	12.5
Other	80	0	20
Handling	53.8	23.1	23.1

Water Immersion	14.3	14.3	71.4
All Types of Accident	**56.6**	**31.2**	**12.2**

The correlation between accident severity and pilot rating is scarcely significant*(chi-square*, p=0.044; confidence 95%).

The data on the collateral damage from the various accidents reveal that in addition to the 383 pilots directly involved, seven bystanders and sixteen pilots of other aircrafts involved in collisions were also injured, for a total of 406 people. The data are insufficient to precisely classify the severity of the injuries suffered by these people. No injuries were sustained in thirteen cases.

Discussion

In our study, the weather conditions were a main or contributing cause of 10.1% of accidents: weather conditions alone were the cause of 5.7% of accidents, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than the one reported in paragliding by Zeller[9], who mentions adverse weather conditions as a cause in 19% of paragliding accidents.

This can be explained by the fact that an engine allows to fly frequently and in a much wider variety of weather conditions, so pilots are less likely to risk flying in extreme and hazardous conditions.

Nevertheless, our study clearly shows that the use of an engine influences the accident dynamics.

It can itself be the cause of accidents, it can be an important aggravating factor in the event of an accident or it can also be the direct cause of injuries.

This study shows that takeoff is the most dangerous phase of flight in PPG(32.9% of the accidents took place during this phase of flight; or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase is landing[3,9].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

14% of accidents.

The engine may also aggravate the accident, mainly due to the energy it produces and transmits to the crew, but also because of its weight. It is mounted on a special frame worn by the pilot: the overall weight of the equipment and accompanying power-plant, vary between 20 and 40 kg. In the case of collision, both of these factors synergize to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to 22.5kW; engine thrust is at its highest during takeoff: the phase of flight when PPG accidents occur most frequently.

In certain reports it is explicitly mentioned that it was precisely the energy supplied by the engine which made the impact fatal.

Various reports also describe that pilot errors had been to some extent determined by a state of mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration(increased by the thrust of the engine) may reduce blood supply to the brain, and could cause momentary state of mental confusion or even blackouts at a time when the maximum level of attention is required[10].

In the case of immersion in water, the weight of the engine can drag the pilot rapidly under the surface, without giving him time to free himself from the equipment, making this type of accident particularly feared among paramotor pilots. In our study, this dynamic was responsible for 21.7 % of fatal accidents(71.4% of accidents involving water immersion were fatal) and a serious (non-fatal) case of near-drowning. It is therefore inadvisable to fly a paramotor over or near water; it is essential that pilots, wishing to do so, adopt the use of self-inflating and specially designed safety systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO_2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine[3, 9-17] while in PPG the upper limbs are more frequently affected and spinal injuries are less common.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew. This is due to the thrust of the engine and the weight of the equipment.

shoulder, arm, elbow, forearm, calf, thigh and ankle, while two cases of generalised burnings were the result of actual fires caused by combustion of the engine fuel. In another case, electrical burnings to the chest and one arm were sustained following collision with high voltage power lines. Contact with power lines is an established cause of accidents in paragliding too, while burnings resulting from engine fuel combustion or contact with the engine are specific to PPG.

Indeed PPG is widely believed to be safer than paragliding, and fatal events considered to be rarer than in paragliding[1]. In our study, 6% of accidents were fatal(fatal accidents/ total number of accidents: 23/383).

This figure is not lower than the values cited in literature for paragliding and hang-gliding(table 7) and is however comparable with the 6.1% of fatal paragliding accidents reported by Schulze(2002)[18] in a study very similar to ours, which was conducted using the data from incident reports.

Table 7. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	**Study**	**No. fatalities**	**No. participants**	**% Fatal events**
Paragliding	Krüger-Franke et al.[11].	2	218	0.91%
Paragliding	Schulze et al. [18].	25	409	6.10%
Paragliding	Lautenschlager et al.[19]	1	86	1.16%
Paragliding	Fashing et al.[12]	0	70	0.00%
Hang-gliding	Foray et al [20].	7	200	3.50%

Considering the differences between PPG and paragliding, further research on this sport and related injuries should be conducted separately from paragliding, in separate studies.

The results of this study suggest that further investigation should consider if the use of certain types of safety clothing and equipment can significantly reduce various risks specific to this sport.

The effectiveness of protective gloves to protect against hand injuries, caused by contact with the spinning prop, should be evalued in future studies.

Since many prop strike injuries have been higher on the upper limb, where gloves would not be effective, an even better solution could be to add the so called "safety ring" to the engine cage. The with an auto-inflating flotation device when flying near water. As in paragliding, periodical checking and maintenance of equipment (the wing and lines in particular) is essential. Additionally, in PPG, careful inspection and maintenance of the engine is vital, given that its malfunctioning could represent a cause of major injuries.

This study has some limitations.

First of all since there is no way of finding out exactly how many people knew about the existance of the database, the effect of under-reporting bias, due to the voluntary nature of our data submission, can be hardly estimated .

In addition, beeing the injury reporting form online, only powered paragliders with access to the Internet were able to participate. For this reason, even though most people use the Internet, selection bias cannot be excluded at all.

Finally the lack of a specific question in the form about the kind of injury sustained, might have led to the loss of some data even if in almost all the cases it was possible to obtain detailed information on the type of injuries by a careful reading of the narrative section of the reports. Data analysis was performed only by one researcher with no cross-check.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in paragliding and in hang-gliding[11, 12, 18, 19, 20](table 7).

For these reasons, PPG should be analysed separately from paragliding in distinct studies.

Further research will be useful to confirm the data of this study, to investigate the role of safety equipment such as protective gloves, safety ring and auto-inflating flotation devices and to evaluate the effectiveness of periodical checks of the engine, to reduce certain risks specific to this sport.

The study was conceived by Francesco Feletti and Jeff Goin.

Jeff Goin collected data.

Francesco Feletti carried out statistical analysis and wrote the draft of the manuscript. All authors contributed to critical revisions of the manuscript and approved the final version.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Keywords

Extreme Sports, Paragliding, Sporting injuries, Adventure Sports, Powered Paragliding, Hand Injuries

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Accidents and injuries related to powered paragliding: a cross sectional study

ABSTRACT

Objectives - Powered paragliding and paragliding are two totally different sports, mainly because of the use of an engine in powered paragliding. As a consequence the pattern of injuries caused by each of these two sports may be different.

Setting - To test this hypothesis, we analysed 384 incident reports gathered by the United States Powered Paragliding Association from 1995 to 2012.

The majority of the incidents described occurred in the US, while 26 incidents occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia(Java)(1), Europe (8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1).

Outcome: to identify the most affected body area and the most common type of injury sustained in PPG, and to highlight any differences with respect to paragliding.

Results - The most affected body areas in PPG were the upper limbs(44.5%) followed by the lower limbs(32 %), the back(9.8,%), the head(7%), the pelvis(3.1), the chest(2.7%) and the abdomen (0.7%) ($p < 0,001$).

The engine caused 43 accidents(11.22%) in our study and was responsible for the majority of injuries to the upper limbs.

The number of fatal accidents is not lower than those which occur in paragliding and in hang-gliding.

Conclusions - To help preventing the specific injuries of powered paragliding, the most appropriate equipment should be identified.

The results of this study also suggest that in the future this sport should be analyzed separately from paragliding.

Strengths and limitations of this study

This is the first study in literature on powered paragliding.

We analyzed a large amount of data(384 incident reports) collected from 1995 to 2012.

similar to that of paragliding, the sport from which it derives, under which the crew is suspended by means of long lines. It is a sport on its own right: different because the equipment used includes an engine, worn on the back and held in place by a harness(Fig. 1).

In contrast to paragliding, which is practised over hilly or mountaineous areas, because it requires a descent in order to take off, the PPG can take off from level ground thank to the power of the engine.

It is safer to fly over level ground because there are fewer obstacles, the thermals are not too strong and winds are generally steady.

Furthermore PPG differs from paragliding because the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, therefore in safer and more stable weather conditions.

Compared to other aerial sports, paragliding nevertheless remains the most similar to PPG they both require the pilot to keep the wing inflated by means of his own weight and skill.

PPG was invented in the 1980's and rapidly gained popularity, so much that various national and international competitions have been held throughout the world over the last few years.

In 2007 it was estimated that the sport was practised in the United States alone, by 3000 people[1].

It seems to be a prevalently male sport, judging from the fact that in 2013 the number of female members of the U.S. Powered Paragliding Association, represented only the 2.6% of the total members.

As PPG has grown in popularity, the number of accidents associated with this sport has inevitably increased. Knowing the accident dynamics, the type of injuries sustained and the body area affected is of vital importance for sports medicine, in order to provide an insight into the types of conduct, protective clothing and safety systems, which should be adopted to improve the safety of any given sport.

A careful examination of the literature leads us to conclude that there are no existing studies on this sport in medical literature, except from a case we had previously reported[2]: in a recent literature review[3], this sport is only mentioned among the variety of paragliding, to which it is usually grouped.

Given that the way of flying a paramotor is very different to that of a paraglider, we supposed that the accident and injury types differ greatly between the two sports as a result.

the US Powered Paragliding Association(USPPA) collected using a specific form published on its website[4].

The collection of the data started in 1995: we decided to use all the data available between 1995 and 2012(the starting date of the present study).

The collection of data was primarily thought for accidents in the U.S. but, since USPPA is very popular among powered paragliders worldwide, accidents from other countries were also reported.

The forms submitted had been completed by the pilot involved, by a witness, or by the Association itself based on the information gathered.

The form included: drop-down menu lists, checklists and text fields.

The form consisted of five sections:

1-General information(date, time and place of the accident);

2-Pilot information: including demographic information and details of the pilot's PPG experience;

3-Details on the accident: including a description of the type of accident, the main cause, weather conditions at the time, characteristics of the takeoff and landing area, and details of the pilot's clothing and equipment;

4-Injury information: including the body parts affected, the seriousness of the injury, any medical assistance and possible collateral damage to people or things.

5-Narrative: an extensive description of the event and its consequences.

The form lacked a specific question about the nature of the injuries but a careful reading of the narrative section, allowed to obtain these information from almost all the forms.

When these data were missing they were named as ‘unknown’ in the results.

The reading of the narrative section was carried out by only one researcher.

The data published by the USPPA were public and anonymous; its use for study and publication purposes was authorised beforehand by the USPPA.

The data were analysed using descriptive statistics, using the software Wizard Pro 1.3.27 and the *chi-square* test.

The following definition of injury has been adopted: “any physical complaint sustained by an athlete that results from training or competition, irrespective of the need for medical attention or time lost from sports activities”[5-7].

Each incident report was also given a NACA(National Advisory Committee of Aeronautics) Score:

category.

We subsequently focused on the accidents resulting in injuries(disregarding those with a NACA score of 0), and we divided these into 3 classes based on the severity of the injuries:

1-minor(NACA I, II), usually not requiring emergency medical measures

2-major(NACA III, IV, V, VI), almost always requiring emergency medical measures

3-fatal(NACA VII).

We associated the accidents thus classified with the accident dynamics cited in the incident reports and with the phase of flight in which the accidents occurred. We also explored the correlation between injury severity and pilot rating, and between injury severity and accident dynamics.

Results

At the starting date of the present study, 384 incident reports were available.

One incident report had been submitted twice, therefore one copy was retained and the other was excluded.

The pilots involved in powered paragliding accidents were aged between 24 and 72(average age= 44.5, median= 48, SD= 9.54).

The majority of the accidents described occurred in the US, while 26 occurred elsewhere: Canada(8), Mexico(5), Panama(1), China(1), Japan(1), Malaysia(1), Indonesia (Java)(1), Europe (8): of which Spain(1), Belgium(1), United Kingdom(3), Italy(1), Romania(1), Unknown(1). Only three accidents involved a female pilot.

Pilot injuries were classified according to NACA category(table 1).

Table 1.NACA Score of PPG accidents in this study

Category	Description	Pilots	%
NACA 0	No injury or disease	194	50.6
NACA I	Slight injury or illness. No acute medical intervention necessary	59	15.4
NACA II	Slight to moderately heavy injury or illness. Further diagnostic examination needed or outpatient medical	48	12.5

NACA IV	Heavy injury or illness where rapid development into a life threatening condition can not be excluded. Emergency medical care is required	11	2.9
NACA V	Acute vital(life threatening) danger	5	1.3
NACA VI	Breath and/or cycle stop and/or reanimation		
NACA VII	Death	23	6

The following factors were taken into consideration:, the phase of flight during which the accident took place(table 2), the primary cause(table 3) and the type of accident(table 4).

As for the experience of the pilots involved, pilot rating was distributed as follows: 25.5% PPG2 (pilots who have an experience of 40 or more flights[4]), 13.5% PPG1(experience of 2 flights or more), 15.1% PPG3(experience of 200 or more flights), 9.1% Instructor, 12.8% None, 11.7% Not applicable, 6% Unknown, 1.8% Other.

No statistically significant correlation was found in our sample between accident severity and pilot rating(*chi-square*, p= 0.044).

With reference to the place where the accidents occurred, these are the following data: 70.5% flat terrain, 11.4% not applicable, 8.8% hilly terrain, 2.6% water, 2.6 % mountainous terrain, 2.6% unknown data, 1.3% other.

Table 2. Phase of Flight

Phase of Flight	**Count**	**%**
Takeoff (including inflation and runup)	165	43%
Cruise	107	27.9%
Landing (including approach and after	55	14.3%

Table 3. Primary Cause of Accidents

Primary cause	Tot.	%
Pilot Errors (only)	205	53.5
Mechanical Failure (including fuel exhaustion)	67	17.5
Pilot Error & Weather	17	4.4
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Weather (Gust, Thermal, Rain, Wind increase, etc..).	22	5.7
Not Applicable/unknown	24	4.4
Other (including wake Tight takeoff/LZ Area)	31	1.8

Table 4. Type of Accidents

Type	Tot.	%
Collision with Terrain/Obstruction on Ground	76	19.8
Powerplant Equipment Malfunction	58	15.1
Body contact with spinning prop	43	11.2
Hard Landing	40	10.4
Fall	37	9.7
Wing Malfunction or Deflation	35	9.1
Other	29	7.5
Handling	20	5.2
Line Tangle/Damage	15	3.9
Collision with other Aircraft/Ultralight	14	3.6
Water Immersion	10	2.6
Other/Not Applicable	35	1.5

To identify the most affected body areas and therefore most critical for the development of

region	area	Cases	(number of cases)		injuries
Head	Head	7	Concussions(3), unknown(2), contusions(1), open wounds(1)	18	7%
	Neck	3	Burnings(1), C2 fracture(1), unknown(1)		
	Face	8	Fractures(4>), lacerations(2), burnings(1), other(1)		
Chest	Chest	7	Rib fractures(2), abrasions(1), burnings(1), contusions(1), open wounds(1), unkown(1)	7	2.7%
Upper Limb	Shoulder	32	Fractures(6), open wounds(5), bruising(4), other(3), tendon injuries (3), dislocations(2), lacerations(2), unknown(2), abrasions (1), burnings(1), contusions(1), muscle strains(1), sprains(1)	114	44.5%
	Arm	26	Lacerations(7), burnings(5), contusions(3), fractures(3), unknown(3), open wounds(2), tendon rupture(1), abrasions(1), sprains(1)		
	Forearm	11	Burnings(2), lacerations(2), fractures(2), unknown(2), contusions(1) open wounds(1), soft tissue injuries(1)		
	Wrist	8	Fractures(3), contusions(2), lacerations(1), other(1), sprains(1)		
	Elbow	5	Open wounds(2), abrasions(1), burnings(1), unknown(1)		
	Hand	32	Fractures(17; 11with amputation), open wounds(6), lacerations(3), contusion(2), muscle strains(1), other(1), sprains(1), unknown(1)		
Abdomen	Abdomen	2	Contusion(1), soft tissue(1) ,	2	0.7%
Back	Back	25	Fractures(8), unknown(8), other(3), contusions(2), abrasions(1), burnings(1), muscle strains(1), open wounds(1)	25	9.7%
Pelvis	Pelvis	8	Fractures(4), contusion(1), internal bruising(1), muscle strain(1), other(1)	8	3.1%
Lower Limb	Thigh	13	Fractures(4), contusions(2), lacerations(2), open wounds(2), abrasion(1), burnings(1), unknown(1)	82	32%
	Knee	19	Contusions(4), sprains(4), lacerations(2), ligament ruptures(2), unknown(2), abrasions(1), dislocations(1), meniscus and ligament tears(1), muscle strains(1), others(1)		
	Calf	17	Fractures(7), burnings(2), contusions(2), lacerations(2), unknown(2), wounds(2)		
	Ankle	22	Sprains(8), fractures(5), contusions(3), unknown(3), dislocations(1), ligament ruptures(1), other(1)		
	Foot	11	Fracture(3), unknown(3), contusions(2), other(2), lacerations(1)		

Another two accidents were fatal due to cerebral spine fractures with spinal cord damage.

In four cases, death was caused by severe head trauma. In all remaining cases, death was the result of high-energy multi-trauma, although the reports do not allow us to identify the precise injuries responsible for death.

Most of the injuries were minor ones(NACA I-II) followed by major ones(NACA III-VI) and fatal ones(NACA VII).

No significant difference was found in the distribution of fatal, major and minor injuries among the three main phases of flight(takeoff including inflation and runup, cruise and landing including approach).

With regard to the relationship between accident dynamic and accident severity, accidents due to body contact with spinning prop and wing malfunction/deflation caused prevalently major injuries(NACA III-VI): 55.6% and 56.2% respectively.

Accidents due to water immersion were prevalently fatal(71.4%).

The other dynamics of injuries cause mainly minor injuries(NACAI-II).

A statistical correlation between injury severity and type of accident was found(chi-square, $p < 0.021$; confidence 95%); severity of injuries by type of accident is shown in Table 6.

Table 6. Severity of Injuries by Type of Accident

Type of Accident	Minor (%)	Major (%)	Fatal (%)
Collision with Terrain/Obstruction on Ground	62.5	18.8	18.8
Powerplant Equipment Malfunction	100	0	0
Body contact with spinning prop	44.4	55.6	0
Hard Landing	74.1	22.2	3.7
Fall	54.5	40.9	4.5
Wing Malfunction or Deflation	31.2	56.2	12.5
Other	80	0	20
Handling	53.8	23.1	23.1
Line Tangle/Damage	100	0	0
Collision with other	40	40	20

The correlation between accident severity and pilot rating is scarcely significant(*chi-square*, p=0.044; confidence 95%).

The data on the collateral damage from the various accidents reveal that in addition to the 383 pilots directly involved, seven bystanders and sixteen pilots of other aircrafts involved in collisions were also injured, for a total of 406 people. The data are insufficient to precisely classify the severity of the injuries suffered by these people. No injuries were sustained in thirteen cases.

Discussion

In our study, the weather conditions were a main or contributing cause of 10.1% of accidents: weather conditions alone were the cause of 5.7% of accidents, while the weather conditions contributed to the accident together with pilot error in 4.4% of accidents. This figure is much lower than the one reported in paragliding by Zeller[9], who mentions adverse weather conditions as a cause in 19% of paragliding accidents.

This can be explained by the fact that an engine allows to fly frequently and in a much wider variety of weather conditions, so pilots are less likely to risk flying in extreme and hazardous conditions.

Nevertheless, our study clearly shows that the use of an engine influences the accident dynamics.

It can itself be the cause of accidents, it can be an important aggravating factor in the event of an accident or it can also be the direct cause of injuries.

This study shows that takeoff is the most dangerous phase of flight in PPG (32.9% of the accidents took place during this phase of flight; or 43% if we include those during run-up and inflation, phases which can be considered an integral part of takeoff with a paramotor), while in paragliding, the most dangerous phase is landing[3,9].

This can be explained by the fact that takeoff with a PPG requires a delicate balance between the thrust of the engine, the weight of the crew and the lift of the wing. Additionally, the takeoff from level ground and the prevalently horizontal thrust of the engine results in the pilot moving away from the ground slowly, as opposed to paragliding, where the distance from the ground increases rapidly due to taking off from a slope.

As a result, falling distance remains reduced for much longer during takeoff with a PPG than it does with a paragliding, limiting the possibility of adopting emergency manoeuvres and making the use overall weight of the equipment and accompanying power-plant, vary between 20 and 40 kg. In the case of collision, both of these factors synergize to make the impact more traumatic given that engine displacement varies between 80cc and 250cc and engine power varies between 11 to 22.5kW; engine thrust is at its highest during takeoff: the phase of flight when PPG accidents occur most frequently.

In certain reports it is explicitly mentioned that it was precisely the energy supplied by the engine which made the impact fatal.

Various reports also describe that pilot errors had been to some extent determined by a state of mental confusion suffered by the pilot during the execution of acrobatic stunts.

Steep spirals are extremely dangerous manoeuvres in PPG; the position of the crew and the centrifugal acceleration (increased by the thrust of the engine) may reduce blood supply to the brain, and could cause momentary state of mental confusion or even blackouts at a time when the maximum level of attention is required[10].

In the case of immersion in water, the weight of the engine can drag the pilot rapidly under the surface, without giving him time to free himself from the equipment, making this type of accident particularly feared among paramotor pilots. In our study, this dynamic was responsible for 21.7 % of fatal accidents(71.4% of accidents involving water immersion were fatal) and a serious (non-fatal) case of near-drowning. It is therefore inadvisable to fly a paramotor over or near water; it is essential that pilots, wishing to do so, adopt the use of self-inflating and specially designed safety systems.

These auto-inflating flotation devices are mounted on a paramotor's frame and are activated by a CO2 cartridge which fires upon submersion: so no pilot input is required.

Paragliding injuries mainly involve lower limbs and spine[3, 9-17] while in PPG the upper limbs are more frequently affected and spinal injuries are less common.

The different injury distribution may depend in part on the different flight dynamics and different distribution of the forces acting on the crew. This is due to the thrust of the engine and the weight of the equipment.

The engine is undoubtedly the factor which distinguishes PPG from paragliding in terms of injury type; contact with the propeller caused 43 accidents(11.22%) in our study and was responsible for the majority of injuries to the upper limbs, in particular lesions to the hands(Fig. 2), wrists, Contact with power lines is an established cause of accidents in paragliding too, while burnings resulting from engine fuel combustion or contact with the engine are specific to PPG.

Indeed PPG is widely believed to be safer than paragliding, and fatal events considered to be rarer than in paragliding[1]. In our study, 6% of accidents were fatal (fatal accidents/ total number of accidents: 23/383).

This figure is not lower than the values cited in literature for paragliding and hang-gliding(table 7) and is however comparable with the 6.1% of fatal paragliding accidents reported by Schulze(2002)[18] in a study very similar to ours, which was conducted using the data from incident reports.

Table 7. Studies on Paragliding and Hang-gliding reporting fatal outcome after accidents.

Sport	Study	No. fatalities	No. participants	% Fatal events
Paragliding	Krüger-Franke et al.[11].	2	218	0.91%
Paragliding	Schulze et al.[18].	25	409	6.10%
Paragliding	Lautenschlager et al. [19]	1	86	1.16%
Paragliding	Fashing et al.[12]	0	70	0.00%
Hang-gliding	Foray et al.[20].	7	200	3.50%

Considering the differences between PPG and paragliding, further research on this sport and related injuries should be conducted separately from paragliding, in separate studies.

The results of this study suggest that further investigation should consider if the use of certain types of safety clothing and equipment can significantly reduce various risks specific to this sport.

The effectiveness of protective gloves to protect against hand injuries, caused by contact with the spinning prop, should be evalued in future studies.

Since many prop strike injuries have been higher on the upper limb, where gloves would not be effective, an even better solution could be to add the so called "safety ring" to the engine cage. The safety ring is an aluminum ring, that mounts just forward the radial arms, with the same radius as the prop. The safety ring is designed to make it difficult for an open human hand to reach the prop at full rated thrust and it adds very little in terms of expense and weight to the equipment.

represent a cause of major injuries.

This study has some limitations.

First of all since there is no way of finding out exactly how many people knew about the existance of the database, the effect of under-reporting bias, due to the voluntary nature of our data submission, can be hardly estimated .

In addition, beeing the injury reporting form online, only powered paragliders with access to the Internet were able to participate. For this reason, even though most people use the Internet, selection bias cannot be excluded at all.

Finally the lack of a specific question in the form about the kind of injury sustained, might have led to the loss of some data even if in almost all the cases it was possible to obtain detailed information on the type of injuries by a careful reading of the narrative section of the reports. Data analysis was performed only by one researcher with no cross-check.

Conclusions

This study reveals a pattern of accidents in PPG clearly different from that of paragliding: PPG accidents are more common during takeoff; weather and wind conditions have a lesser influence in causing accidents, the energy from the engine and the weight of the equipment may aggravate accidents.

The pattern of injuries sustained in this sport are distinctive: mostly involving the upper limbs, while those to the spine are less common. Finally, contrary to the belief held up to now by the experts of this sport[1], the number of fatal accidents/number of accidents is not lower than those which occur in paragliding and in hang-gliding[11, 12, 18, 19, 20](table 7).

For these reasons, PPG should be analysed separately from paragliding in distinct studies.

Further research will be useful to confirm the data of this study, to investigate the role of safety equipment such as protective gloves, safety ring and auto-inflating flotation devices and to evaluate the effectiveness of periodical checks of the engine, to reduce certain risks specific to this sport.

Contributorship Statement

The study was conceived by Francesco Feletti and Jeff Goin.

Jeff Goin collected data.

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FIGURE LEGENDS

Fig. 1: Paramotor in flight

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

Figure 1: Paramotor in flight
134x101mm (300 x 300 DPI)

Fig. 2: Serious hand lesions caused by contact with the engine prop: these injuries are specific to powered paragliding.

90x67mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
Yes		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **Yes**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **Yes**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **Yes**	4	Present key elements of study design early in the paper
Setting **Yes**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **Yes**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **Yes**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **Yes**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias **Yes**	9	Describe any efforts to address potential sources of bias
Study size **Yes**	10	Explain how the study size was arrived at
Quantitative variables **Yes**	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **Yes**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **Yes**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **Yes**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **Yes**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **Yes**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses **Yes**	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results **Yes**	18	Summarise key results with reference to study objectives
Limitations **Yes**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **Yes**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **Yes**	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding **Yes**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.