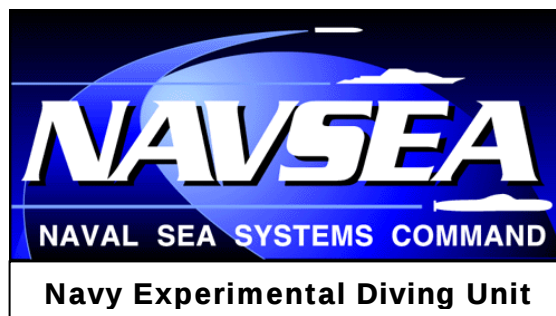


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THE INCIDENCE OF SWIMMING-INDUCED PULMONARY EDEMA (SIPE) IN TRAINEES AT U.S. NAVY DIVE TRAINING FACILITIES



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14. ABSTRACT Swimming-induced pulmonary edema (SIPE) case criteria surveys were distributed to Naval Diving and Salvage Training Center (NDSTC) and Basic Underwater Demolition/SEAL training center (BUD/S). 42 surveys were collected (41 from BUD/S and one from NDSTC). There were approximately 914 NDSTC enrollees and 1440 enrollees at BUD/S. Combining these numbers yields a cumulative cohort of 2354 enrollees. Two of the completed surveys were positive for all five case criteria yielding a 0.085% incidence of SIPE from March 2010 through April 2011 at the two Navy dive training facilities. Considering all completed surveys as cases of SIPE, the incidence increases to 1.78%. There was no correlation between return to duty time, water temperature, activity in the water or number of case criteria positive for SIPE. SIPE remains a potential cause of morbidity and lost training time amongst diving trainees. With proper identification and supportive care, it resolves relatively quickly. Compared to the reported incidence of common musculoskeletal training injuries, the incidence of SIPE at Navy dive training facilities is lower. SIPE is more commonly diagnosed at BUD/S compared to the NDSTC.				
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CONTENTS

DD Form 1473.....	ii
Acknowledgments	iii
Contents.....	iv
Introduction	1
Materials and Methods	2
Data Analysis	2
Results	2
General.....	2
Case Criteria.....	3
Return to Duty Time and Water Temperature.....	3
Activity in the Water	4
SIPE Incidence Rate.....	4
Discussion.....	4
Conclusions.....	5
Recommendations	5
References.....	7
Appendix A: Data sheet.....	A-1
Appendix B: Tabular Data	B-1

INTRODUCTION

Swimming-induced pulmonary edema (SIPE), a form of noncardiogenic pulmonary edema, occurs in otherwise healthy divers and swimmers.¹⁻⁶ SIPE has been reported at various temperatures and activity levels. Military combat divers have developed SIPE during training.¹ Recently it has been estimated that 11 cases of SIPE per year occur at Basic Underwater Demolition/SEAL (BUD/S) training, with 2.2 cases per class and approximately five classes per year.² However, no studies have been performed to investigate the incidence of SIPE at both of the U.S. Navy's major diving training commands — BUD/S, and the Naval Diving and Salvage Training Center (NDSTC).

SIPE often presents with shortness of breath; cough productive of frothy, blood-tinged sputum; and other signs of hypoxia. On examination, one may find cyanosis, decreased partial pressure of oxygen (PO₂) via pulse oximetry, tachypnea, altered level of consciousness, wheezes, rhonchi or rales on auscultation, and radiographic findings consistent with pulmonary edema. With supportive care, SIPE usually improves rapidly (within 24–48 hours); however, in select cases, it has been fatal.³⁻⁴

The exact mechanisms causing SIPE, thought to be a form of pulmonary capillary stress failure,^{1,5} have not been fully explained. Being incredibly thin (~0.2 to 0.3 μm thick), the blood-gas barrier (BGB) in the lungs represents a large surface area (~50–100 m²) that is vulnerable to damage. With increased wall stress and the accompanying damage, the BGB breaks down and allows proteins and fluid to leak into alveoli. This leakage causes pulmonary edema and the symptoms associated with SIPE. The two major mechanisms for increasing the wall stress of pulmonary capillaries are elevated pulmonary capillary pressure and high levels of lung inflation (longitudinal tension). With increased pulmonary capillary pressure, some BGB disruptions were found with transmural pressures as low as 24 mmHg. Among normal subjects participating in severe exercise, Laplace's law and measurements of pulmonary artery wedge pressure found capillary transmural pressures to exceed 25 mmHg.⁵

Risk factors influencing the development of SIPE have been poorly defined. Anecdotally, cold water; overhydration, and intense exercise have been proposed to increase the risk of developing SIPE. During BUD/S, water temperatures are typically between 52 and 72 °F, and trainees undergo intensive physical challenges.² The populations at greatest risk are those whose occupations involve immersion: divers and combat swimmers.

Before the pathophysiology of SIPE is studied, a measurement of its incidence must be determined — to indicate how extensive the problem is and whether Navy-wide recommendations must be formulated to decrease its morbidity. This study sought to satisfy this need by quantifying the cumulative incidence of SIPE at U.S. Navy diving

training facilities (NDSTC and BUD/S) during one calendar year (April 2010 through March 2011).

MATERIALS AND METHODS

The research protocol was approved by the Navy Experimental Diving Unit (NEDU) Institutional Review Board. Data sheets (Appendix A), which were distributed electronically to Diving Medical Officers (DMOs) at NDSTC and BUD/S, were filled out by medical personnel at the two commands as cases of SIPE presented from 1 April 2010 through 31 March 2011. A “yes” or “no” was circled to indicate the presence of each case criterion, and the activity at the time, as well as water temperature and return to duty time, were documented. No personally identifiable information was collected. The sheets were scanned, and E-mailed to the Principal Investigator. At the end of the data collection period, the number of students enrolled at each training command was determined: Student control at NDSTC provided the number of enrollees there, and the student control at BUD/S provided an estimate of the number of students enrolled there for that same past year.

An attempt by the local DMOs to find previous-year case information for SIPE was unsuccessful.

DATA ANALYSIS

SIPE incidence rates were calculated by dividing the number of cases by the number of students enrolled during the year, a quotient which was then converted to a percentage. Basic statistical analysis (mean, median, standard deviation) was completed for the number of SIPE criteria, return to duty time and water temperature. Also, relationships among SIPE criteria, water temperature and return to duty time were evaluated using a lattice diagram.

RESULTS

GENERAL

Forty-two data sheets were collected: 41 from BUD/S, and one from NDSTC. See Appendix B for tabular data from these sheets.

Since NDSTC records its enrollee information on a fiscal-year basis, it could not prospectively record its enrollment figures within this study’s timeframe. The numbers of enrollees vary from year to year (Figure 1), so an average number of 914 students per year (not including fiscal year 2011) was calculated from this data.

<i>Fiscal Year</i>	<i>Number of Enrollees</i>
2006	901
2007	841
2008	1013
2009	895
2010	918
2011	451

Figure 1. Number of trainees enrolled at Naval Diving and Salvage Training Center by fiscal year from 2006 through March 2011.

Similarly, BUD/S was unable to provide exact numbers of enrollees; however, it provided an average number of 1,200 SEAL and 240 Special Warfare Combatant Crewmen (SWCC) students per year, a total of 1,440 BUD/S students per year. Combining the average number of NDSTC students and BUD/S students yields a cumulative total of 2,354 diving trainees in the year of this study.

CASE CRITERIA

Many data sheets were missing information. Thirty-one lacked complete chest x-ray data. Only two collected sheets were marked as positive for all five predetermined case criteria, and varying numbers of case criteria (Figure 2) were met. The average number of case criteria met was 2.55 (median 2, mode 2, SD 1.041).

<i>SIPE Criteria met</i>	<i>n</i>
1	2
2	28
3	1
4	9
5	2
Total	42

Figure 2. Number of positive SIPE case criteria and number of reported cases (n).

All data sheets returned were positive for dyspnea, and all sheets but two were positive for low pulse oximetry. Since the chest x-ray machine was unavailable for many cases, no immediate nor 48-hour x-ray was obtained for these cases. However, when x-rays were obtained, they were positive for opacities. All of these opacities resolved at 48-hour repeat imaging. In all but two cases, there was an immediately preceding history of water aspiration, laryngospasm or preceding infection. Figure 3 is a graphical representation of the relationships between the history of no aspiration and low pulse oximetry case criteria (the only criteria in which all responses were not the same) as well as the return to duty time and water temperature. There are no apparent relationships between these variables.

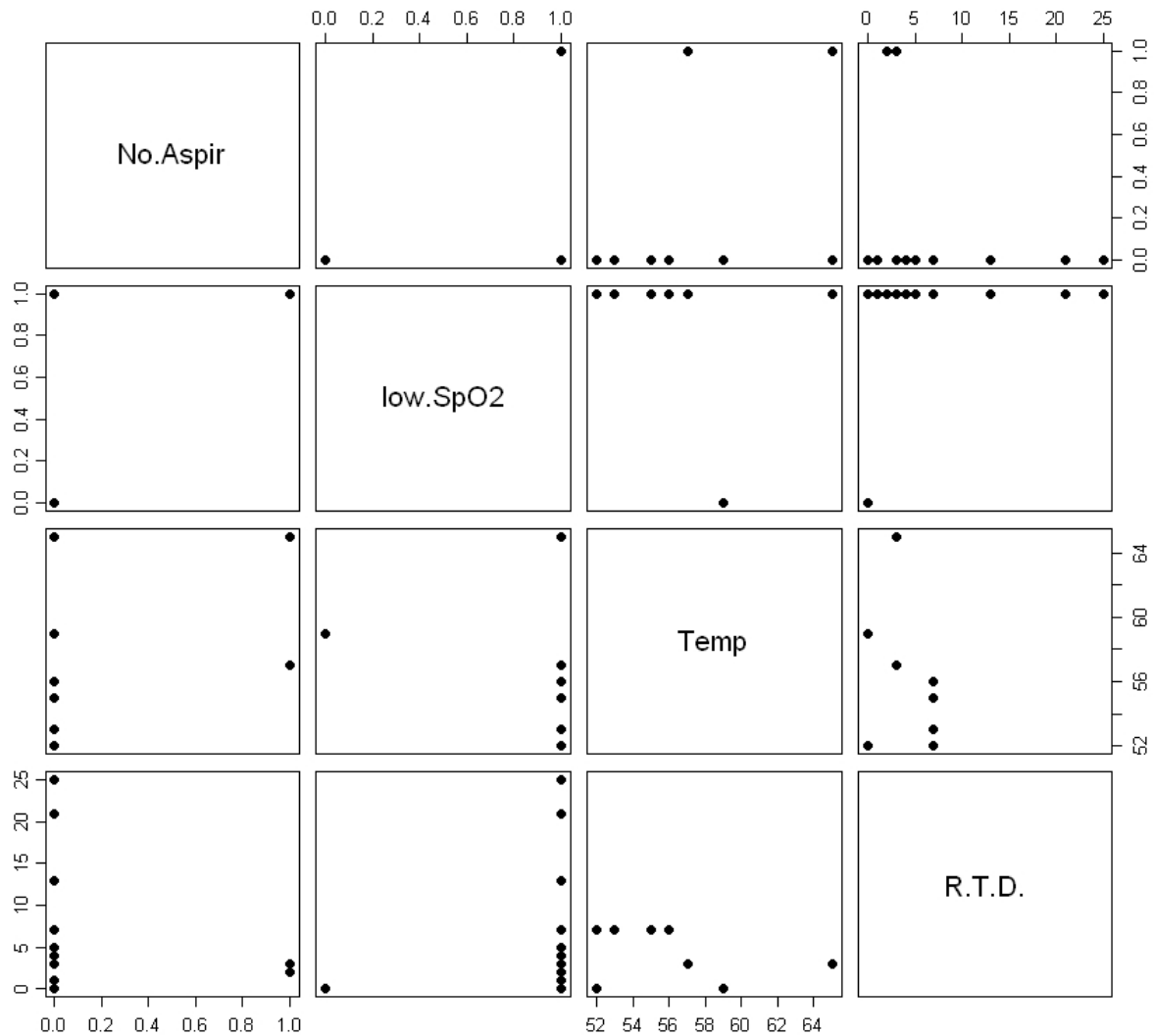


Figure 3 Lattice plot demonstrating relationships between 2 case criteria (No Aspiration (No.Aspir; yes=1, no=0) and Low Pulse oximetry (low.SpO2; yes=1, no=0) with each other as well as water temperature (Temp; in °F) and return to duty time (R.T.D.; in days).

RETURN TO DUTY TIME AND WATER TEMPERATURE

Return to duty times (RTDs) were generally short, with an average time of 5.74 days (median 6 days, mode 7 days, SD 5.042 days). For the long RTDs (21, 25, 14, and 13 days), water temperature was not available, and therefore whether water temperature has any correlation with extended RTDs is unknown. Water temperatures ranged from 52 °F to 65 °F, with an average temperature of 54.9°F (median 53°F, mode 53°F, SD 3.73). Twenty data sheets showed unknown temperatures. The relationship between return to duty time and temperature is represented graphically in Figure 3.

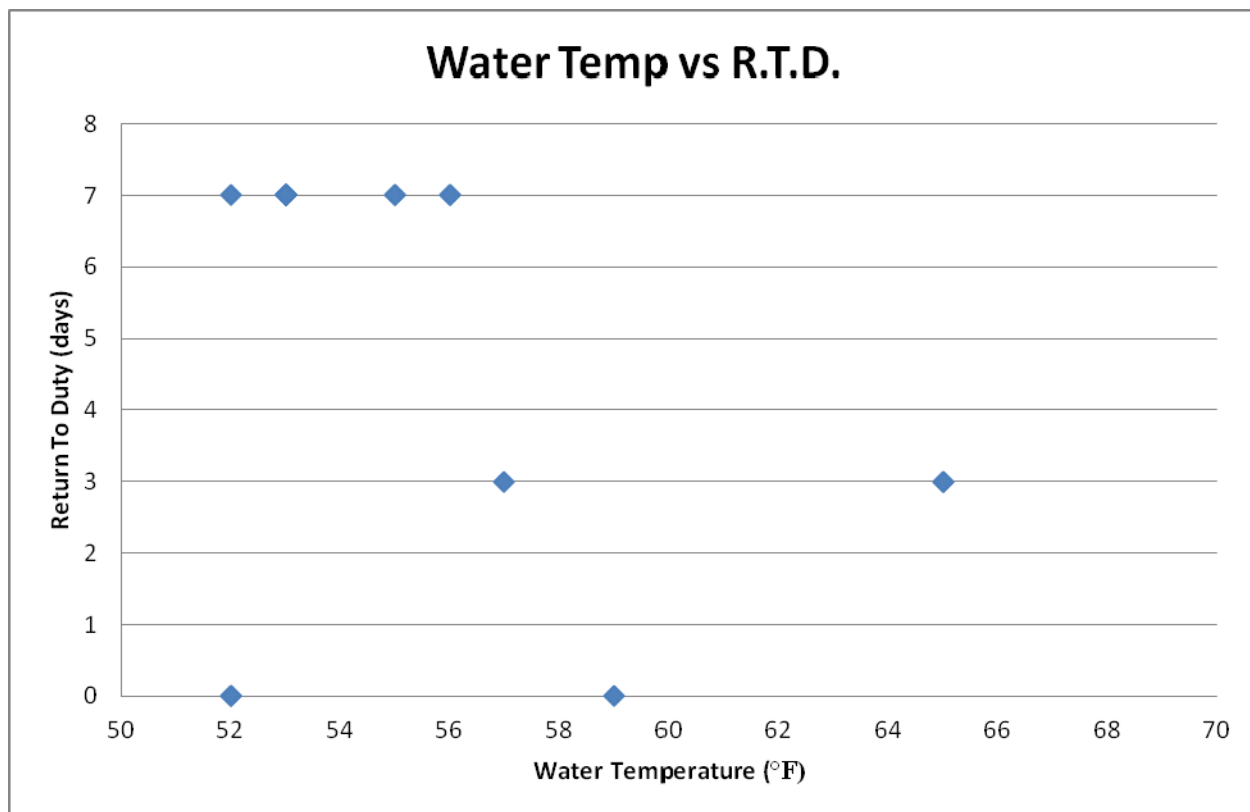


Figure 4: Scatterplot (22 data points) showing Water Temperature vs Return to Duty Time

ACTIVITY IN THE WATER

Varied activities in the water were being performed when the patients developed SIPE. The most common activities (in 24 cases) were during “hellweek” — a varied, week-long evolution during which SEAL trainees exert themselves physically, get little sleep and are exposed to cold water. The second most common (in 16 cases) was “bayfin,” a rigorous 1,000-yard finning evolution. The two cases with 5/5 criteria both presented following bayfins. Other activities in the water included pool physical training (PT) and an ocean swim.

SIPE INCIDENCE RATE

If all data sheets returned are considered cases of SIPE, the approximate incidence of SIPE at BUD/S and NDSTC over the year from 1 April 2010 through 31 March 2011 is 42 cases among 2,354 cumulative trainees — or 0.0178 (1.78%). If only those cases with 5/5 criteria are considered SIPE cases, that number decreases to two cases among those 2,354 cumulative trainees — or 0.000850 (0.0850%).

DISCUSSION

The incidence of SIPE in this study is similar to that found in the civilian tri-athlete population (one survey study demonstrated a prevalence of 1.4%,⁶ an incidence close to the 1.78% (least conservative criteria) observed in this study). In a best-case scenario (0.085% SIPE incidence, most conservative criteria), the Navy's incidence of SIPE is significantly less than that of the civilian triathlete population.

For comparison, a typical cause of lost training time in Naval Special Warfare candidates and Marine recruits is musculoskeletal injury (reported cumulative incidence of 33.1%-36.0% in two studies⁷) which is more common than the observed 1.78% (least conservative criteria) incidence of SIPE in this study. This comparison has its limitations because SIPE infrequently requires inpatient supportive care.

There were several limitations in this study. Many data sheets were incomplete: Approximately 50% of the water temperatures were unknown. Moreover, most data sheets returned did not meet all five SIPE criteria: subjects for 31 of 42 data sheets were unable to get chest x-rays that were required for two of the five criteria.

Most data sheets (39 of 41) returned were positive for an immediately preceding history of water aspiration, laryngospasm or preceding infection. Three of the SIPE case criteria were chosen because they indicate a diagnosis of pulmonary edema, fluid in the alveolar spaces. These criteria include: dyspnea, low pulse oximetry (<90%) or low arterial blood oxygen content, and opacities consistent with an alveolar filling process upon examination with chest x-ray. Since many conditions — including water aspiration, dry drowning, and infection — can cause pulmonary edema, SIPE is a diagnosis of exclusion. To be characterized as a SIPE case, the patient must not have aspirated water, had a laryngospasm, or had a previous infection before presenting for treatment. It is difficult for an immersed person *in extremis* to remember whether or not they aspirated water. This makes the diagnosis of SIPE problematic.

The other challenging issue with this study is the inexact enrollment calculation. Neither training site was able to provide exact numbers over the duration of this study; therefore, the denominator (or total population at risk of SIPE) was estimated.

Navy DMOs, the diagnosing clinicians in this study, receive extensive training and are well qualified to recognize and treat SIPE. Despite this training, SIPE remains diagnostically difficult due to its low incidence and similar presentation to other conditions. The variation in the number of case criteria positive for SIPE may be a result of this difficulty. Physicians at training commands see many musculoskeletal injuries and, in turn, become familiar with the diagnosis. Physicians at diving and swimming training commands must maintain greater vigilance to be familiar and cognizant of SIPE.

CONCLUSIONS

- SIPE remains a potential cause of morbidity and lost training time among diving trainees.
- With proper identification and supportive care, it resolves relatively quickly.
- At Navy dive training facilities, the incidence of SIPE is low, especially when compared to common causes of lost training time.
- SIPE is more commonly diagnosed at the BUD/S training facility than at NDSTC.

RECOMMENDATIONS

- Training commands need to be familiar with SIPE diagnostic criteria and the appropriate therapy.
- SIPE should be aggressively identified and treated with the current standard of care.⁸

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Appendix A: DATA SHEET

CIRCLE CHOICE

Dyspnea or Hemoptysis during or immediately after swimming	YES	NO
No H ₂ O Aspiration, Laryngospasm, or infection	YES	NO
SpO ₂ <92% or an O ₂ gradient of >30 mmHg	YES	NO
Opacities consistent with an alveolar filling process or interstitial pulmonary edema on CXR	YES	NO
CXR findings resolve w/in 48 hours	YES	NO
Site	BUD/S	NDSTC

Activity in H₂O: Diving Timed Swim/Bayfin PT Pool PT Other

Water Temp
(°F): _____

Return-to-Duty Time
(Days): _____

Appendix B: Tabular Data

Dyspnea or Hemoptysis	No H ₂ O Aspiration, laryngospasm or infxn	SpO ₂ <92%	Opacities on CXR	CXR resolves in 48 hours	Site	Activity	Water Temp (°F)	Return to Duty (days)	# of Case Criteria
1	0	0	N/A	N/A	BUD/S	Bayfin	59	0	1
1	0	1	N/A	N/A	BUD/S	Hellweek	52	0	2
1	0	1	N/A	N/A	BUD/S	Hellweek	52	0	2
1	0	1	N/A	N/A	BUD/S	Hellweek	52	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	55	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	55	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	56	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	56	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Hellweek	53	7	2
1	0	1	N/A	N/A	BUD/S	Ocean Swim	Unk	3	2
1	0	1	N/A	N/A	BUD/S	Bayfin	65	3	2
1	1	1	N/A	N/A	BUD/S	Bayfin	65	3	3
1	0	1	N/A	N/A	BUD/S	Hellweek	Unk	21	2

Dyspnea or Hemoptysis	No H ₂ O Aspiration, laryngospasm or infxn	SpO ₂ <92%	Opacities on CXR	CXR resolves in 48 hours	Site	Activity	Water Temp (°F)	Return to Duty (days)	# of Case Criteria
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	3	2
1	0	1	1	1	BUD/S	Hellweek	Unk	25	4
1			N/A	N/A	BUD/S	Hellweek	Unk	14	1
1	0	1	1	1	BUD/S	Bayfin	Unk	4	4
1	0	1	N/A	N/A	BUD/S	Hellweek	Unk	13	2
1	0	1	1	1	BUD/S	Bayfin	Unk	4	4
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	0	2
1	1	1	1	1	BUD/S	Bayfin	Unk	2	5
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	3	2
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	3	2
1	0	1	1	1	BUD/S	Bayfin	Unk	3	4
1	0	1	1	1	BUD/S	Pool PT	Unk	5	4
1	0	1	1	1	BUD/S	Bayfin	Unk	3	4
1	0	1	1	1	BUD/S	Bayfin	Unk	3	4
1	0	1	1	1	BUD/S	Hellweek	Unk	0	4
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	1	2
1	0	1	N/A	N/A	BUD/S	Bayfin	Unk	3	2
1	0	1	1	1	BUD/S	Hellweek	Unk	7	4
1	1	1	1	1	NDSTC	Bayfin	57	3	5