IPA INDEPENDENT PILOTS ASSOCIATION

EXHIBITS

20 - 32

VOLUME II of II

Comments to FAA on Cargo Carve-out in Initial Supplemental Regulatory Impact Analysis

Docket No. FAA-2009-1093

Exhibit 20:

Nat'l Transp. Safety Bd., Aircraft Accident Report: In-Flight Separation of Vertical Stabilizer, American Airlines Flight 587, Airbus Industrie A300-605R, N14053, Belle Harbor, New York, November 12, 2001 (Oct. 26, 2004)
(Excerpted)

In-Flight Separation of Vertical Stabilizer
American Airlines Flight 587
Airbus Industrie A300-605R, N14053
Belle Harbor, New York
November 12, 2001

Aircraft Accident Report

NTSB/AAR-04/04

PB2004-910404
Notation 7439B

National Transportation Safety Board
Washington, D.C.

Aircraft Accident Report

In-Flight Separation of Vertical Stabilizer
American Airlines Flight 587
Airbus Industrie A300-605R, N14053
Belle Harbor, New York
November 12, 2001

NTSB/AAR-04/04
PB2004-910404
Notation 7439B
Adopted October 26, 2004

National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

Contents

Executive Summary

On November 12, 2001, about 0916:15 eastern standard time, American Airlines flight 587, an Airbus Industrie A300-605R, N14053, crashed into a residential area of Belle Harbor, New York, shortly after takeoff from John F. Kennedy International Airport, Jamaica, New York. Flight 587 was a regularly scheduled passenger flight to Las Americas International Airport, Santo Domingo, Dominican Republic, with 2 flight crewmembers, 7 flight attendants, and 251 passengers aboard the airplane. The airplane's vertical stabilizer and rudder separated in flight and were found in Jamaica Bay, about 1 mile north of the main wreckage site. The airplane's engines subsequently separated in flight and were found several blocks north and east of the main wreckage site. All 260 people aboard the airplane and 5 people on the ground were killed, and the airplane was destroyed by impact forces and a postcrash fire. Flight 587 was operating under the provisions of 14 *Code of Federal Regulations* Part 121 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight separation of the vertical stabilizer as a result of the loads beyond ultimate design that were created by the first officer's unnecessary and excessive rudder pedal inputs. Contributing to these rudder pedal inputs were characteristics of the Airbus A300-600 rudder system design and elements of the American Airlines Advanced Aircraft Maneuvering Program.

The safety issues discussed in this report focus on characteristics of the A300-600 rudder control system design, A300-600 rudder pedal inputs at high airspeeds, aircraft-pilot coupling, flight operations at or below an airplane's design maneuvering speed, and upset recovery training programs. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration and the Direction Général de l'Aviation Civile.

1.2 Injuries to Persons

Table 1. Injury chart

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	2	7	251	5	265
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	-	0
Total	2	7	251	5	265

Note: Five fatalities occurred on the ground.

1.3 Damage to Airplane

The airplane was destroyed by impact forces and a postcrash fire.

1.4 Other Damage

In the immediate vicinity of the impact area, four homes were destroyed, three homes received substantial damage, and three homes received minor damage. In addition, the in-flight separation of the engines resulted in property damage where the engines came to rest. A gas station received minor damage as a result of the impact of the left engine, and a home and a boat (parked in the driveway) received severe damage as a result of the impact of the right engine.

1.5 Personnel Information

1.5.1 The Captain

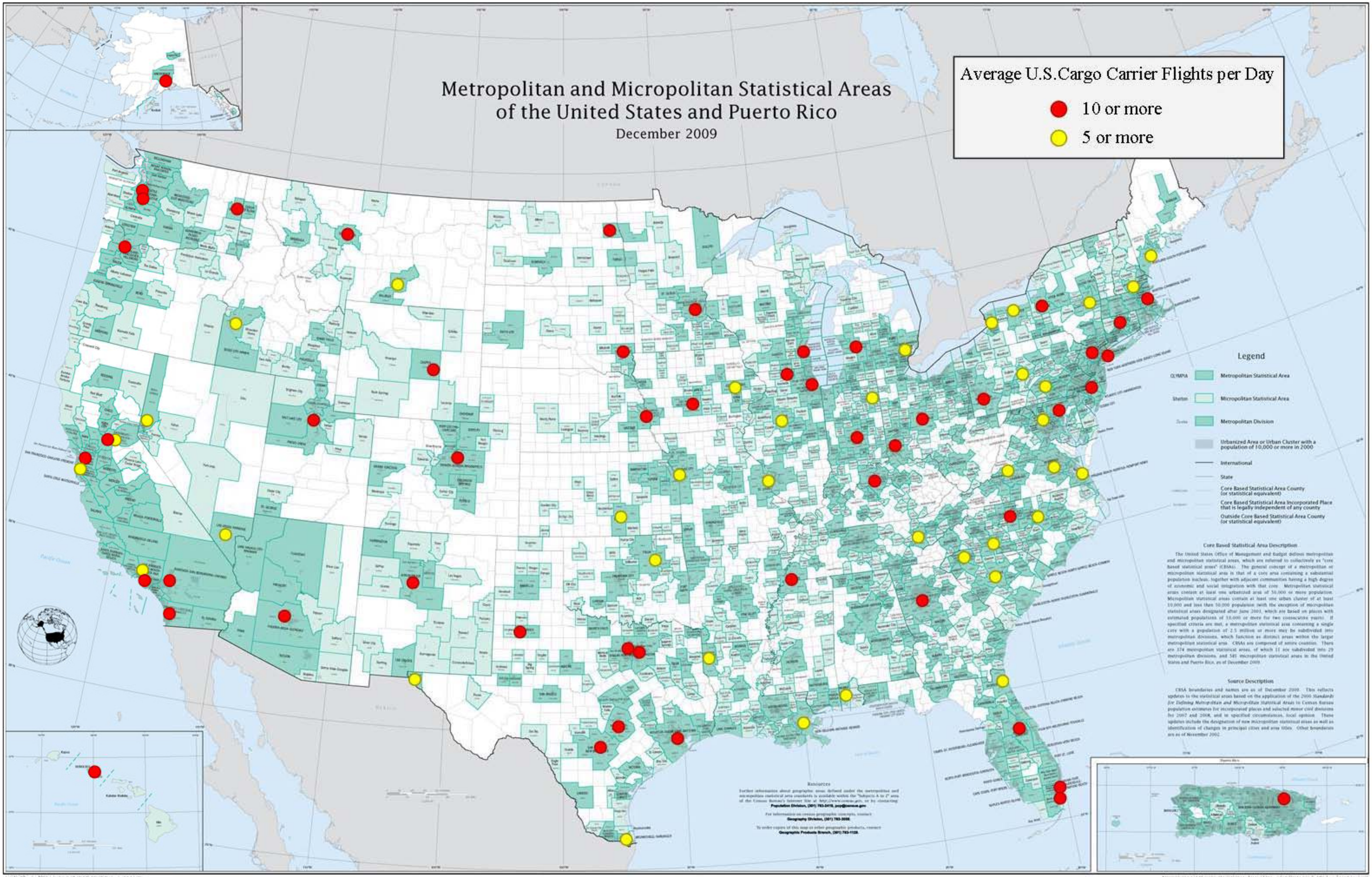
The captain, age 42, was hired by American Airlines in July 1985. He held an airline transport pilot (ATP) certificate and a Federal Aviation Administration (FAA) first-class medical certificate dated June 5, 2001, with no limitations. The captain received a type rating on the A300[23] in September 1988 while serving as a first officer[24] and

[23] The A300 is designated as the A310 on pilot certificates.

[24] Title 14 CFR Section 121.543, "Flight crewmembers at controls," (b) (3) (i), states, in part, that a second-in-command can act as a pilot-in-command during the en route portion of the flight if the pilot holds an ATP certificate and an appropriate type rating, is currently qualified as pilot-in-command or second-in-command, and is qualified as pilot-in-command of that aircraft during the en route cruise portion of the flight.

Exhibit 21:

MSA Cargo Map (Dec. 2009)



Metropolitan and Micropolitan Statistical Areas
of the United States and Puerto Rico
December 2009
Average U.S.Cargo Carrier Flights per Day
10 or more
5 or more
Legend
Metropolitan Statistical Area
Micropolitan Statistical Area
Metropolitan Division
Urbanized Area or Urban Cluster with a population of 10,000 or more in 2000
International
State
Core Based Statistical Area County (or statistical equivalent)
Core Based Statistical Area Incorporated Place that is legally independent of any county
Outside Core Based Statistical Area County (or statistical equivalent)
Core Based Statistical Area Description
Source Description
Resources

Exhibit 22:

Hiroko Tabuchi and Mark McDonald, *Pilots Killed in Crash of Cargo Plane in Japan*, New York Times (Mar. 22, 2009)

Pilots Killed in Crash of Cargo Plane in Japan

By HIROKO TABUCHI and MARK McDONALD
Published: March 22, 2009

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TOKYO — A FedEx Express cargo plane burst into flames as it landed Monday morning at Narita International Airport outside Tokyo, and the company confirmed that the pilot and co-pilot had been killed.

Multimedia

Video: Footage of the Crash (nhk.or.jp)

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Times Topics: Plane Crashes

Video of the crash showed a massive fireball erupting from the plane just as it touched down. The plane then veered to its left, skidded off the runway and flipped over. Fire engines rushed to the scene and sprayed the plane with foam.

The aircraft, an MD-11, was coming from Guangzhou, in southern China. The crash occurred shortly before 7 a.m., according to the Japanese transportation ministry.

There were reports on Monday of strong wind gusts at Narita, located 35 miles east of Tokyo. The Kyodo news agency said a local observatory had recorded 43-mile-per-hour winds.

Runway A, the longer of two landing strips at Narita, was immediately closed and dozens of flights were canceled or rerouted to Haneda, another Tokyo-area airport, and to airports in Osaka and Nagoya. Narita is Japan's busiest cargo hub, and one of the busiest in the world. It also handles most of the international passenger traffic in and out of Japan.

A statement from FedEx confirmed that only two people, the pilot and the co-pilot, had been on board. "We are sad to report that there were no survivors," the statement said.

A police spokesman, Yoshino Ichihara, said FedEx had identified the pilot as Kevin Kyle Mosley, 54, and the co-pilot as Anthony Stephen-Pino, 49. The company's statement on its Web site did not include the names.

Hiroko Tabuchi reported from Tokyo, and Mark McDonald from Hong Kong.

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Past Coverage

Pilots Killed in Crash of FedEx Plane in Japan (March 24, 2009)
Cargo Plane With 7 Aboard Crashes in Iraq (November 14, 2008)
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Exhibit 23:

Crash Site Cleanup Cost $850,000, Pittsburgh Tribune-Review (Sept. 11, 2002)

Crash site cleanup cost $850,000

By The Tribune-Review Wednesday, September 11, 2002

The state Department of Environmental Protection has approved the final cleanup report for the United Airlines Flight 93 crash site near Shanksville in Somerset County.

"United Airlines did a thorough job in its investigation of the environmental effects from the September 2001 plane crash," said Charles A. Duritsa, the DEP southwest regional director.

"Site samples indicate that the site meets Pennsylvania's Act 2 statewide health standards for soil and groundwater for the fuel known as jet "A" fuel. We consider cleanup work at the site completed."

Betsy Mallison, a DEP spokeswoman, said it cost United Airlines $850,000 for the environmental investigation and remediation at the site of the crash in an old strip mine.

The site became a burial ground for 40 passengers and crew members who died after the jetliner was hijacked by four terrorists one year ago today.

United Airlines' site investigation included tests on samples of soil, sediment and groundwater in the immediate crash impact area, and also in the areas lying in the south and southeast corners of the site. The areas tested included a sediment pond drained during the FBI site investigation.

Soil sampling areas included the excavated pit, the area surrounding the pit and the backfill material.

"The backfill material was made up mostly of soil and dirt excavated from the pit during the criminal investigation," Duritsa said.

The material was in an area most likely to be contaminated by jet fuel, he said.

"Tests showed the area is considered safe," Duritsa added.

Soil sampling was conducted in a grid pattern and samples were collected down to 6 inches, according to the DEP. A geoprobe was used throughout the crash site to evaluate deeper impacts. Groundwater samples were collected from four monitoring wells installed in the zone.

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Exhibit 24:

Documentation for IPA Cost Calculations

Documention for IPA Cost Calculations

Scheduling Cost Computations

	Total Crew Members (Table C.1)	After Reduction For Reserves and Non-flyers	Final Rule Ann Cost per Crewmember (FAA Table 21)	Net Scheduling Costs	UPS CH Adjustment for Lines Below Guarantee**	Total Scheduling Costs	Cargo-Only Operations % (Table C.1 population pro-rated)	Cargo-Only Operations Ann Scheduling Costs
Freight NB	846	635	$4,555.16	$2,892,526.60		$2,892,527	85.48%	$2,472,666
Freight WB	914	686	$3,434.88	$2,356,327.68		$2,356,328	78.60%	$1,852,012
Supplemental	1,674	1256	$15,132.52	$19,006,445.12		$19,006,445	70.37%	$13,374,565
Freight Integrated	7,230	3,734*	$5,176.24	$19,328,080.16	($1,983,562)	$17,344,518	100.00%	$17,344,518
Total	10,664	6,311		$41,599,818		$41,599,818		**$35,043,761**

* = Based on actual measured lineholder number for Freight Integrated category. For other categories, based on FAA Assumption of 15% Reserves and IPA Assumption of 10% Non-flyers.

** = $1,416.83 per year per UPS lineholder

Total Nominal Flight Operations Costs, Cargo-Only Ops (Table 25 corrected)

		Scheduling	Programming	Fatigue Call Reduction	Total
	2012				
	2013		$2,000,000		$2,000,000
	2014	$35,043,761		($4,370,000)	$30,673,761
	2015	$35,043,761		($4,370,000)	$30,673,761
	2016	$35,043,761		($4,370,000)	$30,673,761
	2017	$35,043,761		($4,370,000)	$30,673,761
	2018	$35,043,761		($4,370,000)	$30,673,761
	2019	$35,043,761		($4,370,000)	$30,673,761
	2020	$35,043,761		($4,370,000)	$30,673,761
	2021	$35,043,761		($4,370,000)	$30,673,761
	2022	$35,043,761		($4,370,000)	$30,673,761
	2023	$35,043,761		($4,370,000)	$30,673,761
TOTAL		$350,437,608	$2,000,000	($43,700,000)	**$308,737,608**

Table 25: Total Flight Operations Costs, Cargo-Only Operations

Year	Scheduling Cost (millions)	Computer Programming Cost (millions)	Payroll Cost Savings from Reducing Fatigue (millions)	Total Nominal Cost (millions)
2012				$0
2013		$2		$2
2014	$52		-$4	$48
2015	$52		-$4	$48
2016	$52		-$4	$48
2017	$52		-$4	$48
2018	$52		-$4	$48
2019	$52		-$4	$48
2020	$52		-$4	$48
2021	$52		-$4	$48
2022	$52		-$4	$48
2023	$52		-$4	$48
Total	$521	$2	-$44	$479

Total Nominal Crew Rest Facility Costs, Cargo-Only Ops (Table 30 corrected)

	Engineering	Installation	Downtime	Fuel	Total
2012					$0
2013	$1,000,000	$2,250,000			$3,250,000
2014		$2,250,000		$21,825	$2,271,825
2015				$21,825	$21,825
2016				$21,825	$21,825
2017				$21,825	$21,825
2018				$21,825	$21,825
2019				$21,825	$21,825
2020				$21,825	$21,825
2021				$21,825	$21,825
2022				$21,825	$21,825
2023				$21,825	$21,825
TOTAL	$1,000,000	$4,500,000	$0	$218,250	$5,718,250

Table 30: Rest Facilities Total Costs, Cargo-Only Operations

Year	Engineering	Installation	Downtime	Fuel	Total Nominal Cost (millions)
2012	$3				$3
2013		$48	$6	$0	$54
2014				$1	$1
2015				$1	$1
2016				$1	$1
2017				$1	$1
2018				$1	$1
2019				$1	$1
2020				$1	$1
2021				$1	$1
2022				$1	$1
2023				$1	$1
Total	$3	$48	$6	$10	$66

Total Nominal Cost Summary, Cargo-Only Ops (Table 36 corrected)

Flight Operations	$308,737,608
Rest Facilities	$5,718,250
Training	$5,572,897
Total	**$320,028,755**

Table 36: Cost Summary, Cargo-only Operations

Cost Component	Total Nominal Cost (millions)	PV Cost at 7% (millions)	PV Cost at 3% (millions)
Flight Operations	$479	$315	$397
Rest Facilities	$66	$59	$62
Training	$6	$4	$5
Total	$550	$377	$464

Cargo Portion of Operations Calculations

Freight-Integrated	100.00%
Freight Narrow-body	85.48%
Freight Wide-body	78.60%
Supplemental	70.37%

Guarantee Analysis

FAA Freight Integrated CH Increase (CrewPairings Fig. 15, 17)		1.488%
FAA Credit Hour Cost per Freight Int Crewmember per Year (Table 18)	$	4,781.63

13-02 Bid Package

Total Regular Line Credit		221,221
Total Regular Line Pay		224,989
Total Regular Line Pay if each line plussed up 1.488% in credit		227,344
Increase in Regular Pay due to rule		1.047%
FAA Overestimation		42%
FAA Overestimation per Lineholder per Year	$	1,416.83

Figure 15: Case G Monthly Results

Metric	Crew Position	Baseline	Final Rule	Change	
Lines	CA, FE or FO	110	113	3	2.7%
Credit Hours	All	24,551	25,110	560	2.3%
Block Hours	All	10,844	10,829	-15	-0.1%
Aircraft Block Hours	N/A	3,615	3,610	-5	-0.1%

Figure 17: Case H Monthly Results

Metric	Crew Position	Baseline	Final Rule	Change	
Lines	CA or FO	473	480	7	1.5%
	IO	99	102	3	3.0%
	RC	8	7	-1	-12.5%
Credit Hours	All	79,164	80,148	984	1.2%
Block Hours	All	51,348	51,509	161	0.3%
Aircraft Block Hours	N/A	22,910	22,902	-9	0.0%

Table 18: Monthly Change in Flightcrew Scheduling Cost due To Final Rule

Industry Group	Baseline Solution Flightcrew Members	Change in Credit Hour Cost	Change in Domestic TAFB Cost	Change in International TAFB Cost	Change in Hotel Cost	Total Change in Scheduling Cost
Passenger Integrated: Narrow-body	2,622	$270,504	$7,048	$2,346	-$18,460	$261,438
Passenger Integrated: Wide-body	1,551	-$208,842	$7,510	$12,774	$49,205	-$139,353
Passenger Narrow-body	2,622	$280,437	$7,048	$2,346	-$18,460	$271,371
Passenger Wide-body	1,551	-$284,705	$7,510	$12,774	$49,205	-$215,217
Regional	540	$4,953	$15,972	-$31	$24,592	$45,486
Supplemental	806	$930,922	$6,509	$22,270	$56,700	$1,016,401
Freight Integrated	1,383	$551,083	$14,099	$9,330	$22,050	$596,562
Freight Narrow-body	330	$112,588	$1,771	$6,858	$4,050	$125,267
Freight Wide-body	1,053	$268,610	$12,328	$2,472	$18,000	$301,411

Lines

Airline	Lineholders	Total Pilots	Percentage
Federal Express	2,238	4,299	52.06%
UPS	1,400	2,745	51.00%
Total	**3,638**	**7,044**	**51.65%**

Operator	Industry Group	Crewmembers	PercPax	PercCargo	Source: FAA Vital Information Subsystem, December 2010
ABX AIR INC	Freight Integrated	313	0%	100%	
FEDERAL EXPRESS CORP	Freight Integrated	4,227	0%	100%	
UNITED PARCEL SERVICE CO	Freight Integrated	2,690	0%	100%	
AEKO KULA INC (Aloha Air Cargo)	Freight Narrow-body	22	0%	100%	
AERO MICRONESIA INC (Asia Pacific Airlines)	Freight Narrow-body	17	0%	100%	
AIR TRANSPORT INTERNATIONAL LIMITED LIABILITY CO	Freight Narrow-body	208	17%	83%	
AMERIJET INTERNATIONAL INC	Freight Narrow-body	72	0%	100%	
AMERISTAR AIR CARGO INC	Freight Narrow-body	17	17%	83%	
ASTAR USA INC	Freight Narrow-body	120	0%	100%	
CAPITAL CARGO INTERNATIONAL AIRLINES INC	Freight Narrow-body	140	0%	100%	
CARIBBEAN SUN AIRLINES INC	Freight Narrow-body	8	100%	0%	fleet type is similar to freight narrow-body case and aircraft utilization is assumed to be more like freight narrow-body case than passenger narrow-body or regional case
DYNAMIC AIRWAYS LLC	Freight Narrow-body	8	100%	0%	aircraft utilization is assumed to be more like freight narrow-body case than passenger narrow-body or regional case
FALCON AIR EXPRESS INC	Freight Narrow-body	25	100%	0%	aircraft utilization is assumed to be more like freight narrow-body case than passenger narrow-body or regional case
KALITTA CHARTERS II LLC	Freight Narrow-body	35	0%	100%	
LYNDEN AIR CARGO L L C	Freight Narrow-body	77	0%	100%	
NATIONAL AIR CARGO GROUP INC	Freight Narrow-body	31	5%	95%	
NORTHERN AIR CARGO INC	Freight Narrow-body	24	0%	100%	
SIERRA PACIFIC AIRLINES INC	Freight Narrow-body	10	100%	0%	aircraft utilization is assumed to be more like freight narrow-body case than passenger narrow-body or regional case
SKY KING INC	Freight Narrow-body	32	100%	0%	aircraft utilization is assumed to be more like freight narrow-body case than passenger narrow-body or regional case
ATLAS AIR INC	Freight Wide-body	531	2%	98%	CBA is assumed to be more like freight wide-body case than supplemental case and operation kind listed on airline certificate is domestic and flag
NORTH AMERICAN AIRLINES	Freight Wide-body	185	100%	0%	CBA is assumed to be more like freight wide-body case than supplemental case, operation kind listed on airline certificate is domestic and flag, and aircraft utilization is assumed to be more like freight wide-body case than passenger wide-body case
POLAR AIR CARGO WORLDWIDE INC	Freight Wide-body	198	0%	100%	CBA is assumed to be more like freight wide-body case than supplemental case and operation kind listed on airline certificate is domestic and flag
ALASKA AIRLINES INC	Passenger Integrated	1,420	99%	1%	
AMERICAN AIRLINES INC	Passenger Integrated	9,463	100%	0%	
CONTINENTAL AIRLINES INC	Passenger Integrated	4,103	100%	0%	
DELTA AIR LINES INC	Passenger Integrated	10,791	100%	0%	
HAWAIIAN AIRLINES INC	Passenger Integrated	403	100%	0%	
UNITED AIR LINES INC	Passenger Integrated	5,456	100%	0%	
US AIRWAYS INC	Passenger Integrated	4,377	100%	0%	

AIRTRAN AIRWAYS INC	Passenger Narrow-body	1,683	100%	0%	
ALLEGIANT AIR LLC	Passenger Narrow-body	326	100%	0%	
BRENDAN AIRWAYS LLC (USA 3000)	Passenger Narrow-body	54	100%	0%	
CONTINENTAL MICRONESIA INC	Passenger Narrow-body	123	100%	0%	
FRONTIER AIRLINES INC	Passenger Narrow-body	681	100%	0%	
JETBLUE AIRWAYS CORPORATION	Passenger Narrow-body	1,979	100%	0%	
MIAMI AIR INTERNATIONAL INC	Passenger Narrow-body	80	100%	0%	
MN AIRLINES LLC (Sun Country)	Passenger Narrow-body	143	100%	0%	
SOUTHWEST AIRLINES CO	Passenger Narrow-body	5,885	100%	0%	
SPIRIT AIRLINES INC	Passenger Narrow-body	453	100%	0%	
SWIFT AIR L L C	Passenger Narrow-body	27	100%	0%	CBA is assumed to be more like passenger narrow-body case than freight narrow-body case
TEM ENTERPRISES INC (Casino Express)	Passenger Narrow-body	40	100%	0%	
VIRGIN AMERICA INC	Passenger Narrow-body	330	100%	0%	
VISION AIRLINES INC	Passenger Narrow-body	95	100%	0%	
RYAN INTERNATIONAL AIRLINES INC	Passenger Wide-body	150	100%	0%	
AERODYNAMICS INC	Regional	5	100%	0%	
AIR WISCONSIN AIRLINES CORPORATION	Regional	753	100%	0%	
AMERICAN EAGLE AIRLINES INC	Regional	2,525	100%	0%	
ATLANTIC SOUTHEAST AIRLINES INC	Regional	1,668	100%	0%	
AVIATION SERVICES LTD (Freedom Air)	Regional	7	97%	3%	
CHAMPLAIN ENTERPRISES INC (CommutAir)	Regional	163	100%	0%	
CHAUTAUQUA AIRLINES INC	Regional	638	100%	0%	
COLGAN AIR INC	Regional	440	100%	0%	
COMAIR INC	Regional	1,037	100%	0%	
COMPASS AIRLINES LLC	Regional	408	100%	0%	
EMPIRE AIRLINES INC	Regional	45	0%	100%	CBA is assumed to be more like regional case than freight narrow-body case
ERA AVIATION INC	Regional	54	100%	0%	
EXECUTIVE AIRLINES INC	Regional	286	100%	0%	
EXPRESSJET AIRLINES INC	Regional	2,100	100%	0%	
GOJET AIRLINES LLC	Regional	246	100%	0%	
GREAT LAKES AVIATION LTD	Regional	292	100%	0%	
GULF AND CARIBBEAN CARGO INC	Regional	48	0%	100%	CBA is assumed to be more like regional case than freight narrow-body case
GULFSTREAM INTERNATIONAL AIRLINES INC	Regional	158	100%	0%	
HAWAII ISLAND AIR INC (Island Air Hawaii)	Regional	38	100%	0%	
HORIZON AIR INDUSTRIES INC	Regional	621	100%	0%	
HYANNIS AIR SERVICE INC (Cape Air)	Regional	13	98%	2%	
LYNX AVIATION INC (Frontier)	Regional	29	100%	0%	
MESA AIRLINES INC	Regional	1,257	100%	0%	
MESABA AVIATION INC	Regional	935	100%	0%	
MOUNTAIN AIR CARGO INC	Regional	54	0%	100%	
PENINSULA AIRWAYS INC	Regional	80	93%	7%	
PIEDMONT AIRLINES INC	Regional	505	100%	0%	

PINNACLE AIRLINES INC	Regional	1,255	100%	0%	
PRESCOTT SUPPORT CO	Regional	10	0%	100%	CBA is assumed to be more like regional case than freight narrow-body case
PSA AIRLINES INC	Regional	517	100%	0%	
REPUBLIC AIRLINES INC	Regional	681	100%	0%	
RHOADES AVIATION INC	Regional	2	0%	100%	
SEABORNE VIRGIN ISLAND INC	Regional	25	100%	0%	
SHUTTLE AMERICA CORPORATION	Regional	525	100%	0%	
SKYWEST AIRLINES INC	Regional	2,746	100%	0%	
TATONDUK OUTFITTERS LTD	Regional	56	11%	89%	CBA is assumed to be more like regional case than freight narrow-body case
TRANS STATES AIRLINES LLC	Regional	237	100%	0%	
USA JET AIRLINES INC	Regional	52	26%	74%	CBA is assumed to be more like regional case than freight narrow-body case
CENTURION AIR CARGO INC	Supplemental	47	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
EVERGREEN INTERNATIONAL AIRLINES INC	Supplemental	185	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
FLORIDA WEST INTERNATIONAL AIRWAYS INC	Supplemental	32	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
KALITTA AIR LLC	Supplemental	334	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
OMNI AIR INTERNATIONAL INC	Supplemental	315	100%	0%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
SKY LEASE I INC (Tradewinds Airlines)	Supplemental	59	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
SOUTHERN AIR INC	Supplemental	281	0%	100%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental
WORLD AIRWAYS INC	Supplemental	421	43%	57%	Fleet type is similar to supplemental case and operation kind listed on airline certificate is supplemental

Exhibit 25:

ALPA FedEx July 2011 SIG Notes

Scheduling Committee
FedEx-Scheduling@alpa.org

July 2011 SIG Notes

*Due to the feedback we received, below you will find the July SIG Notes reformatted.

SIG PROCESS RECAP:

Summary of the Build: Since January, there has been measured modifications in domestic pairing design for the MEM domiciled A300 and MD11. These two MEM bidpacks make up roughly 60% of all the flying in our system. Since January 2011, this change is captured with the following:
- increase in number of pairing/occurrences < 10:30 CH in the MD11,
- decrease in number of pairings/occurrences > 10:30 CH in the MD11,
- decrease in number of double deadhead pairings/occurrences in the MD11,
- a large number of un-turnable pairings in the A300 (largely the result of one way aircraft routings by ALS),

The result more short trips (MD11), more un-turnable trips (A300) and more departures per line on average (both). The reserve coverage for shorter MD11 trips, in turn, requires the shorter blocks of rdays needed to cover these trips. Consequently, the shorter blocks of rdays increase the number of rday patterns for a given month. Your ALPA SIG is continuing to work with the company to try and correct these problems going forward. These issues are key to improving both pilot alertness, pilot efficiency and your quality of life.

Pairing Assessment Process: The ALPA SIG/PSIT assessed over 2000 pairings during the pairing review process. Approximately 27% of the 2000+ pairings were new or changed between the prelims and finals. The ALPA/SIG PSIT requested for change over 440+ pairings and worked with the company to reconfigure many pairing sequences for better utilization both from a crewforce and company perspective.

- **International Pairings**: We remain concerned about the continued construction of pairings that don't provide a reset after an ocean crossing until well into the pairing. Optimally, we would like to see a reset within the first two layovers in theater. If you fly one of these sequences, please provide us a sleep log or feedback so we can evaluate it.

- **Domestic Pairings**: We continue to focus on the day/night swaps within a pairing. Fly safe! We are working with the company to reduce the number of day/night swaps as well as addressing the alertness issues concerning this type of construction.

Disputed Pairing Process: Of the 440+ pairings requested for change, approximately 1/3 were in the final phase and over 160+ pairings were assessed as part of the dispute process. The SIG (company and ALPA members) worked to find solutions on many of the potential disputes. In the end, this process resulted in 3 disputed pairings in the MEM MD11 and 777 bidpacks.

Scheduling Committee PIREP: We have a web-form to provide the crewforce a mechanism to communicate your scheduling feedback to the ALPA SIG and PSIT. It captures the data from your selections and then forwards the report in an email to your respective PSIT. Your feedback will then be de-identified and consolidated with others to further substantiate our efforts with the Company. **Please consider this our primary means of feedback.**

Sleep Logs: We have new sleep logs, by domicile, on the new Scheduling Committee website. This information is invaluable and is one of our ways to fight fatiguing pairing design. Please take a few minutes on your trip to annotate when you slept and send it to your respective PSIT.

About the SIG: The SIG Notes are a joint document created, vetted and edited with both the union and company involved. For the Jul11 bid period, Crew Resource Planning (CRP) generated the construction of all monthly pairings and the ALPA Scheduling Committee members that serve on the Pilot Scheduling Improvement Teams (PSIT) reviewed those pairings and constructed the **regular lines** in the bidpacks. Comments on the secondary and reserve lines should be directed to Company SIG Chairman, Pat DiMento, at PMDiMento@fedex.com and copy your respective PSIT. Feedback regarding the April 2011 bidpacks and regular lines should be directed to your respective PSIT via a Scheduling Committee PIREP (see above).

Disputed Pairings

MEM 777 Prg #5 on 05JUL11
Prg #51 on 12JUL11, 19JUL11, 26JUL11
MEM MD-11 Prg #250 on 07JUL11

ALPA Scheduling Improvement Group - Fedex-Sig@alpa.org

Rich Hughey, ALPA FedEx MEC Scheduling Committee Chairman
Bill Soer, ALPA FedEx MEC Scheduling Committee Vice-Chairman
JD Oliver, ALPA FedEx MEC Scheduling Committee Knowledge Manager
Mark Stafiej, Trip Services Committee Chairman
Mike Pearcy, Trip Services Committee Vice Chairman

PSIT Notes

A300 HKG

	Captain	First Officer
Average BLG CH	72+36	72+36

RLG CH	69+45	69+45
R-day value CH	4+39	4+39
# of Regular Lines	37 (66%)	37 (63%)
# of Secondary Lines	8 (14%)	11 (19%)
# of Reserve Lines	11 (20%)	11 (18%)
Total # of Lines	56	59
Total CH Available (no c/o)	2740	2740
Avg CH/Rday	16.6	16.6
Carry-in CH from Mar	356	356
% of carry-in to Total CHs	12.9%	12.9%

Disputes: None

PSIT Notes:

The target BLGs for July were 72:00 for the Capt's and the F/O's. There are no differences in pairings for the two bid packs. The paring construction this month allowed for a good mix of lines.
As you recall from last month, we are concerned with some flight sequences that we believe are a alertness issue. Last month, we worked to correct the sequence of DEL-CAN-MNL hub turn before it was operated on the line. This month we addressed the KUL-CAN-ICN hub turn, which also had 7+ block and 11+ duty. The flights from KUL-CAN will now either layover in CAN, or hub turn into shorter flights such as HAN or PVG. This reduces the duty and block to acceptable limits. As with any complex system, changing one thing for the better will cause a ripple effect elsewhere, but overall we feel that pairing construction is much better this month. We will continue to focus on reducing night hub turns that exceed 11 hours of duty time.
PEN is still a layover on Sunday and when starting or finishing in PEN with a deadhead. During the weekdays however, it will only be a day hotel room before returning to KUL for the overnight. BKK will remain a 4 hour hotel sit with the only layovers occurring on DH's.

Thank you to the pilots who have provided SIG PIREPS this month. These reports have helped highlight some of the issues with China Southern Airlines. We have also moved up some front end DH's that were getting in after midnight to providing more rest opportunities. GT continues to be limited to either the front or back, but not both. We also limited HKG–CAN same duty GT to our shorter outbound flights like MNL.
The flying in Asia is constantly changing, and it is important that we hear from you about any safety or alertness issues via the Scheduling Committee PIREP. If you feel fatigue could be an issue, don't hesitate to use the sleep logs found on the FDX ALPA website. The feedback that we receive from you, the line pilot, is instrumental in making any changes to our flying. We need your assistance in order to give you the best possible product.
We appreciate the feedback we're receiving from many of you each month. Please know your comments, good or bad, are welcome. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,
Rick McMullen
Kevin Kelly
FedexA300HKG@alpa.org

A300 MEM

	Captain	First Officer
Average BLG CH	73:06	73:06
RLG CH	70:15	70:15
R-day value CH	4:41	4:41
# of Regular Lines	255 (62%)	255 (67%)
# of Secondary Lines	74 (18%)	51 (13%)
# of Reserve Lines	82 (20%)	76 (20%)
Total # of Lines	411	382
Total CH Available (no c/o)	19487	19487
Avg CH/Rday	15.8	17.0
Carry-in CH from Feb	875	875
Feb CH carry-in to Total CHs	4.4%	4.4%

Disputes: None

PSIT Notes:

July is a four week month this year with a holiday on the first day of the bid month. This affected the carry in credit available for last month and also resulted in a shorter week for building the first week. With the seasonal shorter flight times to the west coast, several cities are now a short layover on the day-side and a 36 hour layover on the night side. This enabled us to build more contiguous lines for these cities. Other 3 and even 4 leg sequences, 24 hour layovers, and the many un-turnable pairings are creating more departures per line and adversely affecting the overall quality of the bidpack. We are attempting to build lines in preparation for the pending NPRM rule changes. If you encounter any alertness issues please file a POR and Scheduling Committee PIREP.

The PM out and backs were missing the first day in the first week due to the Fourth holiday so we had to build them a little different to get them up to the proper BLG.

We appreciate the feedback we're receiving from many of you each month. Please know your comments, good or bad, are welcome. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,

Mike Pearcy
Chip Fox
Robin Sebasco

Harry Edwards
FedexA300Mem@alpa.org

B727 MEM

	Captain	First Officer	Second Officer
Average BLG CH	72+06	72+06	72+06
RLG CH	69+15	69+15	69+15
R-day value CH	4+37	4+37	4+37
# of Regular Lines	88 (53%)	88 (55%)	88 (54%)
# of Secondary Lines	25 (15%)	22 (14%)	18 (11%)
# of Reserve Lines	52 (32%)	50 (31%)	56 (35%)
Total Lines	165	160	162
Total CH Available (no c/o)	6678	6678	6678
Avg CH/Rday	8.5	8.9	7.9
Carry-in CH from Feb	144	144	144
Feb CH carry-in to Total CHs	2.2%	2.2%	2.2%

Disputes: None

PSIT Notes:

July is a four week month with Independence Day falling on the first Monday of the month. The BLG target was 72 CH, with the average coming in at 72+06. Due to the holiday, many of the weekend pairings start with a front end DH. The exception to this was SAV, as there were pairings from SAV that were required to be built into other lines. This is also the reason there are some pairings flown out of the SAV weekend layover. BOS and PIA were again mixed, as BOS cannot turn to itself. In the first week of the month, to make it work with a 4-day work week, a CID pairing had to be put into the mix as well. LFT, which normally operates as a weekend layover was changed to a double-DH design. Because the DH's on both ends operated on Sunday, there was a 1-in-7 issue with building it with LFT DH's on both ends. We've asked the company to return this to a weekend layover.

We appreciate the feedback we're receiving each month. Please continue to send your comments, good and bad. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,

Tom Rutledge
Curt Henry
J D Oliver
Fedex757+727MEM@ALPA.org

B757 MEM

	Captain	First Officer
Average BLG CH	75+00	75+00
RLG CH	72+00	72+00
R-day value CH	4+48	4+48
# of Regular Lines	80 (73%)	80 (75%)
# of Secondary Lines	23 (14%)	19 (12%)
# of Reserve Lines	19 (13%)	18 (13%)
Total # of Lines	102	97
Total CH Available (no c/o)	6345	6345
Avg CH/Rday	22.3	23.5
Carry-in CH from Mar	511	511
% of carry-in to Total CHs	7.75%	7.75%

Disputes: None

PSIT Notes:

The Average BLG target remains at a comfortably high 75 CH. We say that meaning that targets any higher would begin to mean adding unmatched and unconnected filler pairings to "natural" lines. By next month, we hope to have a clearer picture of how fast the CGN base will stand up and what it might mean for the domestic 757 in terms of BLG averages in the short term.
We are still trying to work with the company to improve the EMEA lines which have been trending downhill. Our precepts for those pairings are to mix BUD with night BSL for the shortest duty period, keep pure the day BSL, BCN, and MUC lines, swap out the expiring crews as they pass through CDG, and avoid mid-trip deadheads on the weekend layovers. In addition, we are trying to keep the optimizer from choosing poor ocean crossing deadheads on planes with substandard first/business class seating.

The Thurs/Fri day GFK issue was fixed by the company and those lines now build correctly. In fact, that's our pick city of the month. Look at lines 56 and 57 for a day flying weekend line. The weekend starts with the Saturday afternoon flight instead of the usual Saturday morning. A walk along the Red River of the North followed by a cool one at the Blue Moose Lodge is a wonderful way to spend a July day on the company's dime!

We appreciate the feedback we're receiving from many of you each month. Please know your comments, good and bad, are welcome. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,

J.D. Oliver
Paul Hanson

Curtis Henry
Fedex757+727MEM@ALPA.org

MD-11 ANC

	Captain	First Officer
Average BLG CH	**74:30**	**74:10**
RLG CH	**71:30**	**71:15**
R-day value CH	**4:46**	**4:45**
# of Regular Lines	**54 (50%)**	**94 (61%)**
# of Secondary Lines	**28 (25%)**	**30 (19%)**
# of Reserve Lines	**28 (25%)**	**31 (20%)**
Total # of Lines	**108**	**155**
Total CHs no c/o	**4595**	**7452**
Avg CHS/Rday	**10.9**	**16.5**
Carry-in CH from Mar	**884**	**1262**
% of carry-in to Total CHs	**11.2%**	**11.1%**

Disputes: None

PSIT Notes:

Happy Fourth of July.

July is a 4 week month with the Fourth of July holiday occurring on the first day of the bid month. Overall, credit hours are down compared to the last 4 week month with front seat hours taking the brunt of this reduction. While this reduction is historically normal in ANC, front seat credit hours (not including carryover) are down almost 800 hours. Consequently, we were not able to build as many Captain lines as in previous months. Initial analysis shows a slight increase in hours in both the LAX and MEM MD-11 domiciles. We have been informed by the company that this reduction does not signify an on-going trend.

This month there are a number of pairings that contain the KIX-PEK-ICN duty period. This duty is particularly tough because there are frequent delays both into and out of PEK which can make for a long duty day. In the past, most of these have had a longer layover prior to this duty period. Some of our pairings this month have a very short 15 hour layover preceding it and long duties afterward. We have concerns that the alertness level may cross a threshold that we do not want to be operating in. If you fly on of these pairings and have any issues, we would appreciate it if you would fill out a POR AND a Scheduling Committee PIREP and/or sleep log that shows how you dealt with this duty before and after the short layovers.

Pairing 104 was initially put up for dispute for the number/difficulty of duties and clock swaps after the reset. It will be revised to fix this and be available in its new form for open time. It will probably have a new pairing number assigned to it.

We appreciate the feedback we're receiving from many of you each month. Please know your comments, good and bad, are welcome. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,
+11
Brian Lessin
Cody Chenoweth
Jeff Sparks
FedexMD11ANC@alpa.org

MD-11 LAX

	Captain	First Officer
Average BLG CH	**74+43**	**74+11**
RLG CH	**71+45**	**71+15**
R-day value CH	**4+47**	**4+45**
# of Regular Lines	**45 (58%)**	**47 (55%)**
# of Secondary Lines	**12 (16%)**	**18 (21%)**
# of Reserve Lines	**20 (26%)**	**21 (24%)**
Total # of Lines	**77**	**86**
Total CH Available (no c/o)	**3645**	**3863**
Avg CH/Rday	**12.2**	**12.3**
Carry-in CH from Mar	**831**	**831**
% of carry-in to Total CHs	**18.6%**	**17.7%**

Disputes: None

PSIT Notes:

July is a 4 week bid month. Your PSIT constructed the lines this month and we were requested to build Captain lines to a BLG of 75 hours and First Officer lines to a BLG of 74 hours. We built them to average 74:43 and 74:11 respectively. We initially had 25 out of 85 pairings submitted for changes. Throughout the build week, we were able to get all of the pairing either fixed or modified.

In the July bid month, the July 4th holiday is on the first Monday of the bid month. This caused most of the domestic pairings to begin on either Tuesday or Wednesday of the first week, which in turn made it impossible to build pure week on/week off domestic lines due to the smaller trip credit hours available for these trips on the first week on the month. This led to the addition of smaller trips during the off weeks to build up line credit hours in order to meet the target BLG.

Please remember that Marty Harrington, Andrew Minney and I are constantly pursuing opportunities to improve the LAX bid pack, and your feedback on line and pairing construction to FedexMD11LAX@alpa.org is always highly appreciated and welcome. In addition, you can always contact your ALPA Scheduling Chairman, Rich Hughey, at Fedex-SIG@alpa.org, or the company SIG chairman, Pat DiMento, at PMDimento@fedex.com with any constructive comments or concerns you might have.

Please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

Andrew Minney
Marty Harrington
Chip Brown

MD-11 MEM

	Captain	**First Officer**
Average BLG CH	**74:46**	**74:31**
RLG CH	**90:53**	**89:18**
R-day value CH	**4:47**	**4:42**
# of Regular Lines	**352 (66%)**	**410 (65%)**
# of Secondary Lines	**98 (18%)**	**111 (18%)**
# of Reserve Lines	**85 (16%)**	**110 (17%)**
Total # of Lines	**535**	**631**
Total CHs no c/o	**24367**	**32757**
Avg CHS/Rday	**19.1**	**19.9**
Carry-in CH from Mar	**1545**	**1545**
% of carry-in to Total CHs	**5.9%**	**4.5%**

Disputes: **250/07JUL11**

Pairing 250 is disputed this month due to cumulative fatigue issues. This pairing begins with the afternoon launch to HNL into a deadhead but not before a rolling body clock of 4 hours. A long deadhead to GUM follows into a rolling body clock of 8 hours into an evening hub turn. We then begin night hub turns through TPE the first night and then through CAN.

Notice at this point there is no reset in the pairing and the CAN night hub turn has a block of 7+18 in a 10+55 duty period. We feel that a reset should occur before this duty period.

PSIT Notes:

July is a four-week bid month. The company requested a target BLG of 75 credit hours for Captains and 74 credit hours for First Officers. We built the lines to an average BLG of 74+46/74+31 respectively. We begin the month with a holiday, the 4th of July. This created more deadheads on Monday and Tuesday..

MHT returned to the MD11/10 this month, along with RDU as a new city.

Charter flying continues with NSY, RTA and BAH.

We appreciate the feedback we're receiving from many of you each month. Please know your comments, good and bad, are welcome. The Scheduling Committee PIREP is our primary means of tracking issues since the company doesn't share reports with us. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,
Pat Hagerty
Charlie Sutton
Jami Weaver
Dave McCormick
Keith Knoblauch
Rich Coombs
FedexMD11MEM@alpa.org

MEM 777

	Captain	**First Officer**
Average BLG CH	**81+46**	**82+01**
RLG CH	**78+30**	**78+45**
R-day value CH	**5+14**	**5+15**
# of Regular Lines	**113 (67%)**	**115 (60%)**
# of Secondary Lines	**30 (18%)**	**35 (18%)**
# of Reserve Lines	**25 (15%)**	**43 (22%)**
Total # of Lines	**168**	**193**
Total CHs no c/o	**8682**	**10147**
Avg CHS/Rday	**23.1**	**15.7**
Carry-in CH from Mar	**677**	**904**
% of carry-in to Total CHs	**12.8%**	**10.8%**

Disputes: **5/05JUL11,**
51/12JUL11, 19JUL11, 26JUL11

Pairing 5/5 July – This pairing was disputed for the continuous rolling body clock throughout the entire pairing without a reset. With long duties on three of the four duty periods and the short duty in local base time (LBT) window of circadian low (WOCL), we felt this would be onerous and fatiguing.

Pairing 51/12, 19, & 26 July – This pairing contains four long duty periods with a 24-hour layover between each duty period. This equates to a minimum shift of 8 hours between each duty period, with no reset to help the crewmembers recover. We feel this type of construction will build up cumulative fatigue going into a very long final flight back to Memphis.

PSIT Notes:

Greetings from the B777 PSIT. July is a four-week month with the Independence Day occurring on the first day of the bid month. For the 777, July 4th is another work day, because of our international focus. There is little impact on our schedule. As we have seen the last few months, the average BLG is working its way down. The company requested a BLG target of 81 hours for July. We were able to build to 81:46 for the Captains, and 82:01 for the First Officers.

Issues:

Flying hours: May was the last four-week month, and compared to May, front seat flying for July was 45 hours lower. Relief flying hours, however, showed a shift of 800 hours from First Officers to Captains. In percentage terms, we had a decrease of nearly 1% of front seat flying time, but a 26% increase in Captain RF2 time. For May, 34% of the buildable hours was RF2 time, but in July this number increased to nearly 40% of the buildable hours. This in turn required us to build less pure flying lines. We expect to see this trend reverse in the future as twice as many FO's as Capt are being trained/qualified per month.

On a trial basis, we decided to sort the lines by putting the non-RFO/RF2 lines at the front of the bidpack. We also put the lines containing nothing but RFO/RF2 time at the end of the bidpack. We would like your feedback as to whether you like this line sorting. If you have any other ideas as to how you would like the lines sorted, let us know.

CZ airlines. We have one pairing containing a deadhead on China Southern. We had requested a change to Dragon Air on this pairing, but this would have forced the company to operate the deadhead without a backup, so it was left as is. We continue to solicit your CZ deadhead experiences. If you can add a photo(s) to your write ups, this would be even more helpful.

Pairing Changes:

Pairing 56 has a mid-trip deadhead between CAN and SZX. It will be changed from the current deadhead to a ground transportation directly between the two cities. This pairing operates four times throughout the month, with a Friday departure on each occurrence.

As always, we welcome feedback on pairing construction and line building. We can't emphasize enough that your issues really do get traction, but we can't do anything unless we know about your concerns. Scheduling PIREPs on the ALPA website are invaluable tools in letting us know what needs to be addressed. Remember though that we aren't copied on PORs. Therefore, please submit a Scheduling Committee PIREP anytime you submit a Company Pilot Ops Report and then please CC the report to us here at the PSIT via email. This is the only way we can track data on current issues with any reliability. As always, we welcome your input and feedback on any trip that you operate.

In Unity,

Gregg Hall
Barry Rutberg
Aaron Grady
Fedex777MEM@alpa.org

TRIP SERVICES SOLUTIONS

LAX & HKG MEM Recurrent Training Hotel & Ground Transportation Update – The new Flight Training hotel, The Doubletree, and its associated transportation started with the May Bid Period. The committee was not consulted by the Company prior to this business decision being made. Once the committee was made aware of the decision to use The Doubletree and informed of the renovations made to the hotel the committee agreed to use the hotel as a Flight Training hotel. The biggest concern of the committee regarded the ability of the hotel to meet in a timely manner the transportation needs of our LAX & HKG recurrent training crewmembers. The committee was successful in getting the Company to agree to "on demand" hotel shuttle transportation to the respective training facilities. In spite of some initial transportation issues the Company has indicated both the hotel and its shuttle are meeting the needs of our crewmembers. If you have issues with either the hotel or its transportation, please contact the Flight Training Travel Desk @ 901-397-9045. They can also be reached via e-mail @ trainingtravel@fedex.com. David Moore, Manager Flight Training Scheduling, can be contacted if you have issues the Flight Training Travel Desk is unable to resolve. His e-mail address is drmoore@fedex.com.

Hotel Notes:

CDG Update – The 4th downtown hotel located in the La Defense area will commence with the August Bid Period and will be announced via FCIF.

DUS Update – When Crew Travel Services and the committee were informed by Crew Resource Planning & Analysis of the need for a DUS layover hotel a couple of months ago it was with the intention of using the hotel for short (i.e. < 18 hours) layovers in conjunction with deadheads. Based on this information, both Crew Travel Services and the committee inspected airport hotels. Long DUS layovers will be revised to have the GT moved to the same duty period as the deadhead flights to enable a CGN versus a DUS layover.

DXB Update – The Company announced via FCIF 11-0279 (Hotel) that DXB layovers would move from our current contract hotel, **The Crowne Plaza Dubai**, to the **Sheraton Dubai Creek Hotel & Towers** for the month of June. The committee requested the Sheraton in an effort to receive crewmember feedback on this property as a potential replacement for the Crowne Plaza next year. Please provide POR feedback to the Company on the Sheraton.

EWR Update - As mentioned in last month's Trip Services Solutions, the committee asked the Company to terminate the contract with the **Hotel Indigo at Skyview** due to the large number of negative e-mails received by the committee as well as negative Pilot Ops Reports received by Crew Travel Services. As a temporary replacement for the Hotel Indigo, the Company issued FCIF 11-0252 (Hotel) announcing the **La Quinta Secaucus** would be used until a site inspection was completed by both the Company and the committee. The La Quinta will be used for June Bid Period layovers only. The Company has completed its inspections and once the committee completes its inspections the Company will issue an FCIF announcing the new hotel. The new hotel will be effective with the July Bid Period. The La Quinta Secaucus will not be inspected by the committee as a potential contract hotel!

GUM Update – The **Guam Hilton** will continue to be used as a non-contract hotel until the Company and the committee can complete their respective inspections. Please continue to provide POR feedback to the Company on the Guam Hilton.

RDU Update – The contract with the **Marriott Crabtree Valley Hotel** has been extended until December 31st, 2011.

TLC Update – Due to negative correspondence received by the committee as well as negative PORs received by Crew Travel Services, it was decided to not renew the contract with our long time TLC hotel, The Del Rey Inn Hotel. The Company and committee have completed their respective inspections and the new contract hotel will be announced via FCIF in the coming weeks.

Pilot Ops Report (POR) – The most efficient way for management to be made aware of and correct issues pertaining to hotels, catering and ground transportation is via the Pilot Ops Report (POR). This electronic form is accessed via the pilot.fedex.com website home page. If you have a hotel, catering or ground transportation concern/issue, positive or negative, we encourage you to submit the report. These Ops Reports, combined with your correspondence to the Trip Services Committee, are reviewed at our quarterly meetings with the Company and are instrumental in making changes. We encourage input. Please e-mail us at Fedex-Hotel@alpa.org..

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Exhibit 26

Final IPA Benefit-Cost Analysis and Methodology

FINAL IPA BENEFIT-COST ANALYSIS

BASE CASE*

Benefits Summary—Base Case (Dollars In Millions)			
Range	**Nominal**	**7%**	**3%**
Lower Bound	**$19.6**	**$12.9**	**$16.3**
Mid-point	$253.2	$166.2	$209.7
Upper Bound	**$486.8**	**$319.5**	**$403.1**
IPA Cost	$320.0	$212.2	$266.2
Net Benefit			
Lower Bound	**-$300.4**	**-$199.4**	**-$249.9**
Mid-point	**-$66.8**	**-$46.**	**-$56.5**
Upper Bound	**$166.7**	**$107.3**	**$137.0**

Benefits Summary—Base Case with Rough Order-of-Magnitude Estimate for Qualitative and Tangible Benefits (Dollars In Millions)			
Range	**Nominal**	**7%**	**3%**
Lower Bound	**$81.6**	**$53.6**	**$67.6**
Mid-point	$346.2	$227.2	$286.7
Upper Bound	**$610.8**	**$400.9**	**$505.8**
IPA Cost	$320.0	$212.2	$266.2
Net Benefit			
Lower Bound	**-$238.4**	**-$158.7**	**-$198.6**
Mid-point	**$26.2**	**$15.0**	**$20.6**
Upper Bound	**$290.7**	**$188.7**	**$239.7**

* Lack of sufficient information precluded developing discrete estimate for certain qualitative and tangible benefits. Using best judgment, these have been conservatively monetized to the extent practicable by applying per annum during the 10-year benefit period, a rough-order-of-magnitude estimate equal to the value of a statistical life ($6.2 million) for the lower bound, and twice this value ($12.4 million) per annum for the upper bound. Qualitative and tangible impacts captured using this approach include, but are not limited to, avoidance of pilot fatigue-related accidents on the tarmac during taxiing, the presence of more alert pilots in the cockpit who are better able to deal with (1) in-flight anomalies before they become serious and (2) in flight emergencies; the premium value attributed to expedited and perishable cargo, such as pharmaceutical supplies, medical equipment, donor transplant organs and time-sensitive legal and governmental documents; general health improvements of pilots who do not suffer from chronic fatigue, and post-accident delayed health costs from toxic and other chemical substances released as a result of the accident.

FINAL IPA BENEFIT-COST AN ALYSIS

SENSITIVITY CASE—EL AL CRASH CONSEQUNECES FOR UPPER BOUND*

Benefits Summary—Sensitivity Case* (Dollars In Millions)			
Range	**Nominal**	**7%**	**3%**
Lower Bound	**$19.6**	**$12.9**	**$16.3**
Mid-point	$314.7	$206.6	$260.6
Upper Bound	**$609.8**	**$400.3**	**$505.0**
IPA Cost	$320.0	$212.2	$266.2
Net Benefit			
Lower Bound	**-$300.4**	**-$199.4**	**-$249.9**
Mid-point	**-$5.3**	**-$5.7**	**-$5.5**
Upper Bound	**$289.7**	**$188.0**	**$238.8**

* **Uses El Al accident scenario for upper bound.**

Benefits Summary—Sensitivity Case with Rough Order-of-Magnitude Estimate for Qualitative and Tangible Benefits* (Dollars In Millions)			
Range	**Nominal**	**7%**	**3%**
Lower Bound	**$81.6**	**$53.6**	**$67.6**
Mid-point	$407.7	$267.6	$337.6
Upper Bound	**$733.8**	**$481.7**	**$607.7**
IPA Cost	$320.0	$223.4	$280.3
Net Benefit			
Lower Bound	**-$238.4**	**-$169.8**	**-$212.6**
Mid-point	**$87.7**	**$44.2**	**$57.4**
Upper Bound	**$413.7**	**$258.2**	**$327.4**

* **Uses El Al accident scenario for upper bound.**

* The number of fatalities and injuries are consistent with the October 4, 1992 crash of an El Al B-747cargo aircraft while on final approach in Amsterdam, Netherlands. Three crew, one non-crew occupant (sitting in the jump seat), and 43 people on the ground were killed; 11 others were seriously injured. Fortunately, many people were not home on the evening of the crash, reportedly due to the pleasant weather. Otherwise there may have been more than 200 fatalities as was originally estimated by the Dutch government. While not a pilot fatigue-related accident, it is indicative of the plausible catastrophic consequences associated with such events.

BRIEF SUMMARY OF METHODOLOGY TO ESTIMATE BENEFITS

- Conceptualize problem and postulate accident types.
- Postulate applicable accident types:
  - Type I: Lower bound accident on airport property
  - Type II: Lower bound accident off airport property
  - Type III: Upper bound accident on airport property
  - Type IV: Upper bound accident off airport property

For each accident type perform the following:

- Identify all assumptions
- Utilize relevant accident data, to the extent practicable, and expert judgment to derive accident consequences in terms of frequency and consequences, including fatalities, injuries, property damage and environmental clean-up
- Utilize air cargo industry expertise in conjunction with FAA forecasts to identify the type of aircraft that will comprise the cargo fleet during the benefit period and quantify the respective payload capacity and hull value for the typical aircraft
- Identify cargo arrival and departure flight paths and characterize their respective demographics in terms of population and housing in these areas
- Estimate crash site area square footage
- Apply demographic data to crash site area to monetize property damage for each housing and ground impact site area
- Apply Poisson distribution to 20-year accident history to ascertain plausible accident frequency consistent with approach performed by FAA in its RIA
- Apply sensitivity analysis to address uncertainty among estimates for accident frequency and consequences
- Identify tangible consequences to be addressed in ROM estimate, to the extent practicable, estimate due to difficulty estimating
- Identify qualitative consequences to be addressed, to the extent practicable, in ROM estimate due to difficulty estimating
- Apply technical judgment to estimate a range for the ROM
- Replicate the algorithms used by the FAA in its RAA for calculating benefits in nominal and discounted values
- Populate model to derive nominal and discounted benefits over the 10-year benefit period

DIRECT QUALITATIVE AND TANGIBLE BENEFITS MONETIZED IN IPA'S BENEFIT-COST ANALYSIS AS A ROUGH-ORDER-OF-MAGNITUDE ESTIMATE

Qualitative Benefits

1. More alert pilots in the cockpit, able to react swiftly and appropriately to in-flight abnormalities in flight, before they become emergencies, as well as responding better to emergencies.

2. Premium value attributed to expedited and perishable cargo, including pharmaceutical supplies, medical equipment, donor transplant organs, and time-sensitive legal and governmental documents

3. Cumulative effect of chronic sleep loss on physical and mental health resulting in disorders that can reduce the quality of life and productivity, cause an increase use of health-care services, and result in injuries, illness, or deaths.

4. Disruption and inconvenience to accident victims on the ground from loss of house and personal property, including time burden of locating temporary housing and replacing personal items

5. Loss of irreplaceable environmental, historic or otherwise aesthetic property

Tangible Benefits

1. Pilot fatigue-related non-airborne accidents (accidents on the tarmac during taxiing)
2. Revenue losses for failure to deliver cargo and having to refund delivery cost or absorb all re-delivery costs
3. Post-accident health costs from release of toxic and other chemical substances

Exhibit 27:

Nicole Lamond and Drew Dawson, *Quantifying the Performance Impairment Assessment Associated with Fatigue*, 8 J. Sleep Research 255 (1999)

J. Sleep Res. (1999) **8**, 255–262

Quantifying the performance impairment associated with fatigue

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SUMMARY The present study systematically compared the effects of fatigue and alcohol intoxication on a range of neurobehavioural tasks. By doing so, it was possible to quantify the performance impairment associated with fatigue and express it as a blood alcohol impairment equivalent. Twenty-two healthy subjects aged 19–26 years participated in three counterbalanced conditions. In the sustained wakefulness condition, subjects were kept awake for 28 h. In the alcohol and placebo conditions, subjects consumed either an alcoholic or non-alcoholic beverage at 30 min intervals, until their blood alcohol concentration reached 0.10%. In each session, performance was measured at hourly intervals using four tasks from a standardised computer-based test battery. Analysis indicated that the placebo beverage did not significantly effect mean relative performance. In contrast, as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. Similarly, as hours of wakefulness increased performance levels for four of the six parameters significantly decreased. More importantly, equating the performance impairment in the two conditions indicated that, depending on the task measured, approximately 20–25 h of wakefulness produced performance decrements equivalent to those observed at a blood alcohol concentration (BAC) of 0.10%. Overall, these results suggest that moderate levels of fatigue produce performance equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment.

KEYWORDS alcohol intoxication, performance impairment, sustained wakefulness

INTRODUCTION

The negative impact of sleep loss and fatigue on neurobehavioural performance is well documented (Gillberg *et al*. 1994; Mullaney *et al*. 1983; Tilley and Wilkinson 1984). Studies have clearly shown that sustained wakefulness significantly impairs several components of performance, including response latency and variability, speed and accuracy, hand-eye coordination, and decision-making and memory (Babkoff *et al*. 1988; Fiorica *et al*. 1968; Linde and Bergstrom 1992). Nevertheless, understanding of the relative performance decrements produced by sleep loss and fatigue among policy-makers, and within the community, is poor.

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By contrast, the impairing effects of alcohol intoxication are generally well accepted by the community and policy makers, resulting in strong enforcement of laws mandating that individuals whose blood alcohol concentration exceeds a certain level be restricted from driving, working and/or operating dangerous equipment. Consequently, several studies have used alcohol as a standard by which to compare impairment in psychomotor performance caused by other substances (Dick *et al*. 1984; Heishman *et al*. 1989; Thapar *et al*. 1995). By using alcohol as a reference point, such studies have provided more easily grasped results regarding the performance impairment associated with such substances.

In an attempt to provide policy makers and the community with an easily understood index of the relative risks associated with sleep loss and fatigue, Dawson and Reid (1997) equated the performance impairment of fatigue and alcohol intoxication using a computer-based unpredictable tracking task. By doing so, the authors demonstrated that one night of sleep deprivation produces performance impairment greater than is currently acceptable for alcohol intoxication.

While this initial study clearly established that fatigue and alcohol intoxication have quantitatively similar effects, it should be noted that performance on only one task was investigated. Thus, it is unclear at present whether these results are restricted to hand-eye coordination, or characteristic of the general cognitive effects of fatigue. While it is generally accepted that sleep loss and fatigue are associated with impaired neurobehavioural performance, recent research suggests that tasks may differ substantially in their sensitivity to sleep loss. Studies addressing this issue have suggested that tasks which are complex, high in workload, relatively monotonous and which require continuous attention are most vulnerable to sleep deprivation (Johnson 1982; Wilkinson 1964).

As conditions that cause deterioration in one particular function of performance may leave others unaffected, it is unreasonable to assume that one could predict all the effects of sleep loss from a single performance test. Thus, the current study sought to replicate and extend the initial findings of Dawson and Reid (1997) by systematically comparing the effects of fatigue and alcohol intoxication on a range of performance tasks.

METHOD

Subjects

Twenty-two participants aged 19–26 years were recruited for the study using advertisements placed around local universities. Volunteers were required to complete a general health questionnaire and sleep/wake diary prior to the study. Subjects who had a current health problem, and/or a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol were also excluded. Participants were social drinkers who did not regularly consume more than six standard drinks per week.

Performance battery

Neurobehavioural performance was measured using a standardised computer based test battery (developed by WORKSAFE Australia). The apparatus for the battery consisted of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. Based on a standard information processing model (Wickens 1984), the battery sought to provide a broad sampling of various components of neurobehavioural performance. Four of twelve possible performance tests were used, such that the level of cognitive complexity ranged from simple to more complex (as listed below). Since speed and accuracy scores can be effected differently by sleep deprivation (Angus and Heslegrave 1985; Webb and Levy 1982), tasks that assessed both were investigated.

The simple sensory comparison task required participants to focus on an attention fixing spot displayed on the monitor for 750 ms. Following this, a line of stimulus characters, divided into three blocks of either numbers, letters or a mixture was displayed. Participants were then required to respond to a visual cue, which appeared in the position of one of the stimulus blocks, by naming the block which had been there. Verbal responses were scored as correct, partially correct or incorrect.

The unpredictable tracking task (3-min trials) was performed using a joystick to control the position of a tracking cursor by centring it on a constantly moving target. Performance was measured as a percentage of time on target.

The vigilance task (3.5-min trials) required subjects to press one of six black buttons or a single red button, depending on which light was illuminated. If a single light was illuminated subjects were required to press the corresponding black button underneath it. If, however, two lights were illuminated simultaneously subjects were required to press the red button. Each light went off when a response was made, or after 2500 ms. For this report, two vigilance measures were evaluated: (i) the number of correct responses (accuracy), and (ii) increases in the duration of responses (response latency).

The grammatical reasoning task was based on a similar task by Baddeley (1968). This task required subjects to decide and indicate whether a logical statement, which referred to a pair of letters, was true or false (e.g. The statement 'A precedes B' is true for the letter pair AB). For each trial, subjects were presented individually with 32 statements, beneath which were a pair of letters (either AB or BA). To respond, subjects were required to hold down a home button on the response box until they were ready to press one of two other buttons, designated either true or false. Subjects were instructed to concentrate on accuracy, rather than speed. In this report, both accuracy (percentage of correct responses) and response latency were evaluated.

During test sessions, subjects were seated in front of the workstation in an isolated room, free of distraction, and were instructed to complete each task once (tasks were presented in a random order to prevent order effects). Each test session lasted approximately 15 min. Subjects received no feedback during the study, in order to avoid knowledge of results affecting performance levels.

Procedure

Subjects participated in a randomised cross-over design involving three experimental conditions: (i) an alcohol intoxication condition (ii) a placebo condition, and (iii) a sustained wakefulness condition. During the week before commencement of the experimental conditions, all participants were individually trained on the performance battery to familiarise themselves with the tasks and to minimise improvements in performance resulting from learning. Subjects were required to repeat each test until their performance reached a plateau.

The subjects reported to the laboratory at 20.00 h on the night before each condition. Prior to retiring at 23.00 h, subjects were required to complete additional practice trials on each

Table 1 Summary of ANOVA results for neurobehavioural performance variables

	Baseline		*Placebo*		*Alcohol intoxication*		*Sustained wakefulness*	
Performance variable	$F_{2,63}$	*P*	$F_{7,147}$	*P**	$F_{5,105}$	*P**	$F_{13,273}$	*P**
GRG response latency	0.24	NS	0.82	NS	4.96	0.0021	13.77	0.0001
GRG accuracy	2.81	NS	0.63	NS	6.88	0.0001	2.20	NS
VIG response latency	0.24	NS	2.19	NS	43.09	0.0001	33.74	0.0001
VIG accuracy	1.53	NS	2.02	NS	7.99	0.0008	11.04	0.0001
Unpredictable tracking	0.24	NS	2.63†	NS	5.32	0.0008	10.09	0.0001
Simple sensory comparison	0.26	NS	0.78	NS	1.88	NS	1.47	NS

GRG, grammatical reasoning; VIG, vigilance.
* Corrected by Greenhouse–Geisser epsilon; † Based on data from 20 subjects.

task. For each condition subjects were woken at 07.00 h, following a night of sleep, and allowed to breakfast and shower before a baseline testing session, which started at 08.00 h. During each condition subjects had free access to zeitgeibers such as television, radio and clocks.

Alcohol intoxication condition

Subjects completed a performance testing session hourly. Following the 09.00 h testing session, each subject was required to consume an alcoholic beverage, consisting of 40% vodka and a non-caffeinated soft drink mixer, at half hourly intervals. Twenty minutes after the consumption of each drink, BAC were estimated using a standard calibrated breathalyser (Lion Alcolmeter S-D2, Wales) accurate to 0.005% BAC. When a BAC of 0.10% was reached no further alcohol was given. Subjects were not informed of their BAC at anytime during the experimental period.

Placebo condition

The procedure for the placebo condition was essentially identical to the alcohol condition. Subjects in the placebo condition had the rim of their glass dipped in ethanol to give the impression that it contained alcohol. To ensure that subjects remained blind to the treatment condition to which they had been allocated, approximately equal numbers of subjects received alcohol or placebo in any given laboratory session.

Sustained wakefulness condition

In order to produce substantial levels of fatigue, subjects were deprived of sleep for one night and performance was measured at the low point of the circadian cycle. Following the 08.00 h baseline session, subjects completed a performance testing session every hour. In between their testing sessions, subjects could read, write, watch television or converse with other subjects, but were not allowed to exercise, shower or bath. Food and drinks containing caffeine were prohibited the night before and during the experimental conditions.

Statistical analysis

To control for interindividual variability on neurobehavioural performance, test scores for each subject under each condition were expressed relative to the test score they obtained in the baseline (08.00 h) testing session of that condition. Relative scores within each interval (hour of wakefulness or 0.01% BAC intervals) were then averaged to obtain the mean relative performance across subjects. Neurobehavioural performance data in the sustained wakefulness and alcohol intoxication conditions were then collapsed into 2-h bins and 0.02% BAC intervals, respectively.

Evaluation of systematic changes in each performance parameter across time (hours of wakefulness) or blood alcohol concentration were assessed separately by repeated-measures analysis of variance (ANOVA), with significance levels corrected for sphericity by Greenhouse–Geisser epsilon.

Linear regression analysis based on the means over all subjects was used to determine the line of best fit for the performance effects across hours of wakefulness and alcohol intoxication. The relationship between neurobehavioural performance and both hours of wakefulness and BAC was expressed as a percentage drop in performance for each hour of wakefulness or each percentage increase in BAC, respectively. For each performance parameter, the percentage drop in test performance in each of the two conditions was also equated, and the effects of sustained wakefulness on performance expressed as a BAC equivalent.

RESULTS

Baseline scores

To evaluate possible differences between the baseline (08.00 h) measure obtained in each condition, separate ANOVAs for each performance parameter were used. As is evident in Table 1, the baseline measures for each performance variable did not significantly differ as a function of condition.

Table 2 Summary of linear regression analysis of neurobehavioural performance variables

Performance parameter	*DF*	*F*	*P*	*R2*	*% decrease*
SW condition					(per hour)
GRG response latency	1,4	70.61	0.0011	0.95	2.69
GRG accuracy	1,4	3.64	NS	—	—
VIG response latency	1,4	98.54	0.0006	0.96	1.98
VIG accuracy	1,4	81.79	0.0008	0.95	0.61
Unpredictable tracking	1,4	70.93	0.011	0.95	3.36
Simple sensory	1,4	4.71	NS	—	—
Alcohol condition					(per 0.01% BAC)
GRG response latency†	1,2	74.30	0.0132	0.97	2.37
GRG accuracy	1,4	31.07	0.0051	0.89	0.68
VIG response latency	1,4	12.65	0.0002	0.98	2.05
VIG accuracy*	1,3	212.37	0.0007	0.99	0.29
Unpredictable tracking*	1,3	238.52	0.0006	0.99	2.68
Simple sensory	1,4	5.37	NS	—	—

* Based on data from 0.02%–0.10% BAC; † Based on data from 0.04%–0.10% BAC.

Alcohol intoxication condition

Table 1 displays the results of the ANOVAs run on each performance variable as a function of BAC. Five of the six performance parameters significantly ($P = 0.0008–0.0001$) decreased as BAC increased, with poorest performance resulting at a BAC of 0.10% or greater.

The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.02% interval. As is evident in Table 2, there was a significant ($P = 0.0132–0.0002$) linear correlation between BAC and mean relative performance for all of the variables except one. It was found that for each 0.01% increase in BAC, the decrease in performance relative to baseline ranged from 0.29 to 2.68%.

Placebo condition

To ensure that differences in performance reflected only the effects of actual alcohol intoxication a placebo condition was incorporated into the study. As indicated in Table 1, mean relative performance in the placebo condition did not significantly vary.

Sustained wakefulness condition

Table 1 displays the results of the ANOVAs for each performance variable as a function of hours of wakefulness. Four of the six performance parameters showed statistically significant ($P = 0.0001$) variation by hours of wakefulness. In general, the hours-of-wakefulness effect on each performance parameter was associated with poorest performance resulting after 25–27 h of wakefulness.

Since there is a strong non-linear component to the performance data, which remained at a fairly stable level throughout the period which coincides with their normal waking day, the performance decrement per hour of wakefulness was calculated using a linear regression between the 17th (equivalent to 23.00 h) and 27th hour of wakefulness.

As indicated in Table 2, regression analyses revealed a significant linear correlation ($P = 0.0011–0.0001$) between mean relative performance and hours of wakefulness for four of the six performance variables. Between the 17th and 27th hours of wakefulness the decrease in performance relative to baseline ranged from 0.61 to 3.35% per hour (Table 2).

Fatigue and alcohol intoxication

The primary aim of the present study was to express the effects of fatigue on a range of neurobehavioural performance tasks as a blood alcohol equivalent. Figures 1–6 illustrate the comparative effects of alcohol intoxication and fatigue on the six performance parameters. When compared to the impairment of performance caused by alcohol at a BAC of 0.10%, the same degree of impairment was produced after 20.3 (grammatical reasoning response latency), 22.3 (vigilance accuracy), 24.9 (vigilance response latency) or 25.1 (tracking accuracy) hours. Even after 28 h of sustained wakefulness, neither of the remaining two performance variables (grammatical reasoning accuracy and simple sensory comparison) decreased to a level equivalent to the impairment observed at a BAC of 0.10%.

DISCUSSION

In the present study moderate levels of alcohol intoxication had a clearly measurable effect on neurobehavioural performance. We observed that as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. A similar effect was observed in the sustained wakefulness condition. As hours of wakefulness increased performance levels for four of the six parameters significantly decreased. Comparison of the two effects indicated

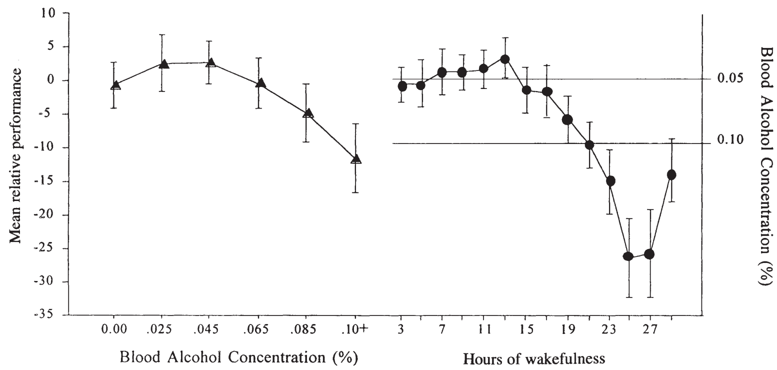

Figure 1. Mean relative performance levels for the response latency component of the grammatical reasoning task in the alcohol intoxication (left) and substained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

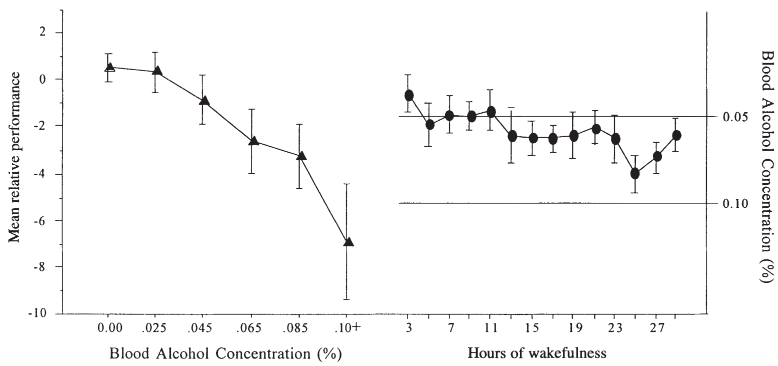

Figure 2. Mean relative performance levels for the accuracy component of the grammatical reasoning task in the alcohol intoxiction (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

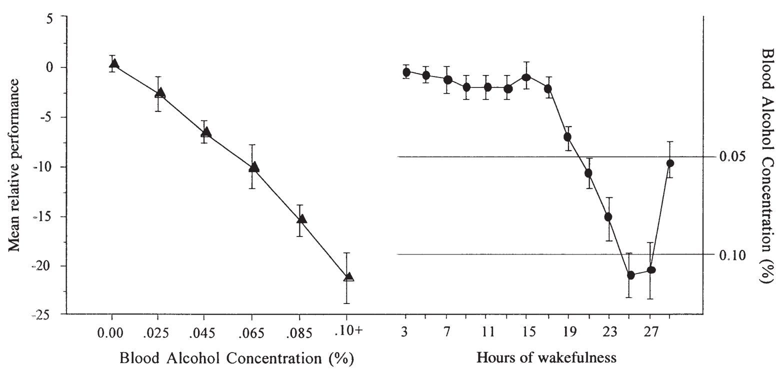

Figure 3. Mean relative performance levels for the response latency component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

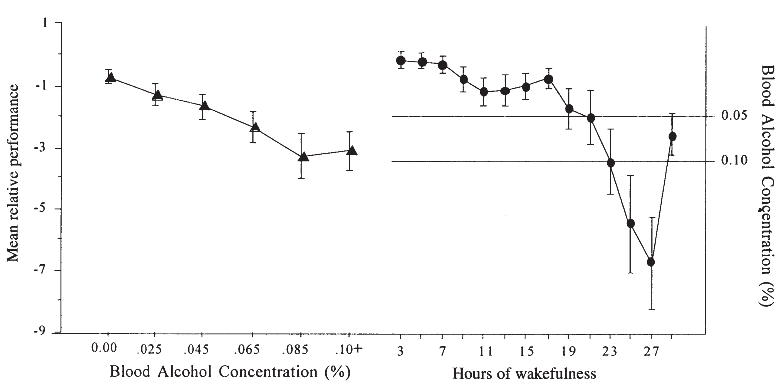

Figure 4. Mean relative performance levels for the accuracy component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% ad 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

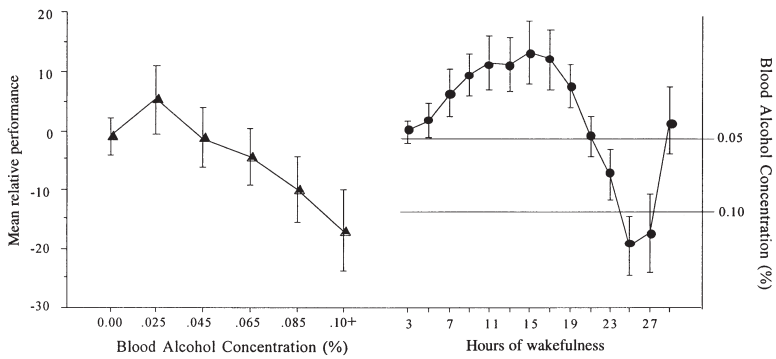

Figure 5. Mean relative performance levels for the unpredictable tracking task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

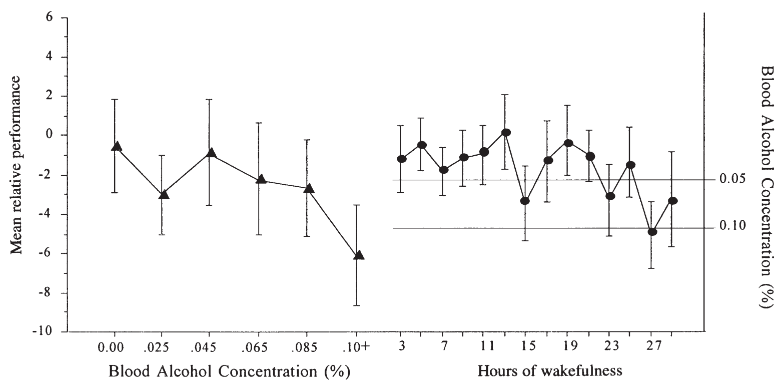

Figure 6. Mean relative performance levels for the simple sensory comparison task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

that moderate levels of fatigue produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

As previous research has found that some individuals tend to perform in a manner that is consistent with the expectation that they are intoxicated due to alcohol consumption (Brechenridge and Dodd 1991), a placebo condition was included in this study. We found that the placebo beverage did not significantly effect mean relative performance. Thus, it was assumed that performance decrements observed during the alcohol condition were caused solely by increasing blood alcohol concentration. Moreover, it is worth noting that the placebo condition in this study generally did not create the perception of alcohol consumption. Furthermore, when participants had already experienced the alcohol condition, and thus the effects of alcohol on their subsequent behaviour and performance, placebo beverages were even less convincing, suggesting that inclusion of a placebo condition is not necessary in future studies of a similar nature.

In general, increasing BAC were associated with a significant linear decrease in neurobehavioural performance. At a BAC of 0.10% mean relative performance was impaired by approximately 6.8% and 14.2% (grammatical reasoning accuracy and response latency, respectively), 2.3% and 20.5% (vigilance accuracy and response latency, respectively) or 21.4% (tracking). Overall, the decline in mean relative performance ranged from approximately 0.29% to 2.68% per 0.01% BAC. These results are consistent with previous findings that suggest that alcohol produces a dose-dependent decrease in neurobehavioural performance (Billings *et al.* 1991).

In contrast, mean relative performance in the sustained wakefulness condition showed three distinct phases. Neurobehavioural performance remained at a relatively stable level during the period which coincided with the normal waking day (0–17 h). In the second phase, performance decreased linearly, with poorest performance generally occurring between 08.00 and 10.00 h, after 25–27 h of wakefulness. It was observed that mean relative performance increased again after 26–28 h of wakefulness presumably reflecting either the well reported circadian variation in neurobehavioural performance (Folkard *et al.* 1993) or, as subjects were aware of the time, an end of testing session effect.

The decrease in performance observed for four of the measures in this study is consistent with previous studies documenting neurobehavioural performance decreases for periods of sustained wakefulness between 12 and 86 h (Linde and Bergstrom 1992; Storer *et al.* 1989; Fiorica *et al.* 1968). Between the 17th and 27th hours of wakefulness, mean relative performance significantly decreased at a rate of approximately 2.61% (grammatical reasoning response latency), 0.61 and 1.98% (vigilance accuracy and response latency, respectively) or 3.36% (tracking) per hour.

While the results in each of the experimental conditions are interesting in themselves, and have previously been established, the primary aim of the present study was to compare the effects of alcohol intoxication and sustained wakefulness. Given that the experimental design meant that a greater number of testing sessions occurred in the sustained wakefulness condition, it was considered possible that boredom related to excessive testing may have contributed to the performance decrement observed. However, given that in the alcohol condition an equivalent, if not greater, effect was observed for four of the six performance variables, we believe it unlikely.

Equating the effects of the two conditions indicated that 17–27 h of sustained wakefulness (from 23.00 to 10.00 h) and moderate alcohol consumption have quantitatively similar effects on neurobehavioural performance. Indeed, the findings of this study suggest that after only 20 h of sustained wakefulness, in the early hours of the morning, performance impairment may be equivalent to that observed at a BAC of 0.10%.

This study has confirmed the suggestion made by Dawson and Reid (1997) that moderate levels of fatigue produce performance decrements equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment. More importantly, however, this study was designed to determine whether the results of Dawson and Reid (1997) were an isolated finding, or characteristic of the general cognitive effects of fatigue. Using the degree of impairment caused by alcohol that produced a BAC of 0.10% as a standard, this study systematically compared the effects of fatigue on a range of neurobehavioural tasks. Results indicate that while, in general, fatigue had a detrimental effect on psychomotor performance, the specific components of performance differed in their degree of sensitivity to sleep deprivation.

The observed differences between the performance tasks with respect to their vulnerability to fatigue can be explained by their relative degrees of complexity. That is to say, the more complex neurobehavioural parameters measured in the present study were more sensitive than were the simpler performance parameters. While only 20.3 h of sustained wakefulness (at 03.00 h) was necessary to produce a performance decrement on the most complex task (grammatical reasoning) equivalent to the impairment observed at a BAC of 0.10%, it was after 22.3 (at 05.00 h) and 24.9 h (at 08.00 h) of sustained wakefulness that a similar result was seen in a less complex task (vigilance accuracy and response latency, respectively). Furthermore, on the unpredictable tracking task, a slightly less complex task than vigilance, a decrement in performance equivalent to that observed at a BAC of 0.10% was produced after 25.1 h of wakefulness (at 08.00 h).

It was observed that despite a slight downward trend performance on the simplest of the four tasks did not significantly decrease, even following 28 h of sustained wakefulness. In contrast, performance on this task was significantly impaired after a dose of alcohol that produced a BAC of 0.10% (or greater). These results are in line with the suggestion that simple tasks are less sensitive to sleep deprivation (Johnson 1982). Indeed, we believe it likely that impairment of performance on this task may have occurred if we had extended the period of sustained wakefulness. It is interesting to note that several studies (e.g. Dinges *et al*. 1988) have reported that tasks similarly lacking in complexity, such as simple reaction time tasks, are affected early and profoundly by sleep loss, thus strongly suggesting that monotony may increase sensitivity to sustained wakefulness. Indeed, the fact that this task was not vulnerable to fatigue may possibly be explained by the interesting and challenging properties of the task.

It is also noteworthy that while we observed a decrease in accuracy on the grammatical reasoning task, impairment of this performance parameter was not comparable to that produced by a BAC of 0.10%. While this may at first contradict the suggestion that in this study vulnerability to fatigue was, to a large degree, determined by task complexity, it should be noted that participants were instructed to concentrate on accuracy rather than speed when completing the grammatical reasoning task. Thus, our particular instructions to participants may explain, at least in part, this irregularity. Alternatively, this finding is in line with the suggestion of a natural speed-accuracy trade-off. Similar results have been observed in several studies, which report a decline in speed of performance, but not accuracy, when sleep-deprived subjects are required to perform a logical-reasoning task (Angus and Heslegrave 1985; Webb and Levy 1982).

Interestingly, this was not the case with the vigilance task. In this instance, despite instruction to concentrate primarily on accuracy, this component was slightly more vulnerable to fatigue than was response latency. The absence of a trade-off on this task may be explained by the different properties of the vigilance and grammatical reasoning tasks. In accordance with the distinction raised by Broadbent (1953), the latter of these tasks can be defined as an unpaced task in which the subject determines the rate of stimuli presentation. In contrast, the vigilance task can be defined as a paced task in which stimuli are presented at a speed controlled by the experimenter. In line with this distinction, our findings are consistent with those of Broadbent (1953) who observed that while a paced task rapidly deteriorated during the experimental period, in terms of speed, an unpaced version of the same task did not.

A further explanation for the differences observed between these two tasks may relate to the extremely monotonous nature of the vigilance task. Indeed, we believe it likely that subjects were more motivated to perform well on the grammatical reasoning task, which was generally considered more interesting and challenging. Hence degree of motivation may explain why measures of both speed and accuracy decreased on the vigilance task, while on the former task accuracy remained relatively stable. This suggestion is in line with previous studies which have found that motivation can, to a degree, counteract the effects of sleep loss (Horne and Pettitt 1985).

It is worth noting that while the effects of alcohol and fatigue were generally similar there were exceptions. As mentioned, it was observed that fatigue had a greater effect on the response time component of the grammatical reasoning task than on the accuracy component. In contrast, despite our instructions to concentrate on accuracy rather than response time the opposite was observed for the alcohol condition. This finding suggests that alcohol and fatigue may have a differential effect on the strategy we instructed individuals to adopt.

Taken together, the results from this study support the suggestion that even moderate levels of fatigue produce performance decrements greater than is currently acceptable for alcohol intoxication. Furthermore, our findings suggest that while fatigue has a generally detrimental effect on neurobehavioural performance, specific components of performance differ in their sensitivity to sustained wakefulness. It is important to note that these levels of fatigue were due to a combination of prior hours of wakefulness and circadian factors. As such, the same amount of prior wakefulness at a different time of day would not produce the same blood alcohol equivalent as that observed in the early hours of the morning.

Since approximately 50% of shift workers typically spend at least 24 h awake on the first night shift in a roster (Tepas *et al.* 1981), our findings have important implications within the shift work industry. Indeed, the results of this study if generalised to an applied setting, suggest that on the first night shift, on a number of tasks, a shift worker would show a neurobehavioural performance decrement similar to or greater than is acceptable for alcohol intoxication.

While the current study supports the idea that fatigue may carry a risk comparable with moderate alcohol intoxication, it is difficult to know to what degree these results can be generalised to real-life settings. Indeed, laboratory measures and environments usually bear little resemblance to actual tasks and settings. Furthermore, while our study used a battery of tests to evaluate the effects of fatigue on performance there is no guarantee that all the functions involved in real-life tasks, such as driving, were utilised and assessed. An alternative approach would be to simulate the actual task as accurately as possible. Given that, for practical and ethical reasons, it is difficult to experimentally study the relationship between fatigue and actual driving, simulators of varying realism have been used. Thus, protocols using simulators could be used to model real-life settings and establish a more accurate estimate of the BAC equivalence for the performance decrement associated with sleep loss and fatigue.

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Exhibit 28:

Adam Fletcher, Nicole Lamond, Cameron J. van den Heuvel, and Drew Dawson, *Prediction of Performance During Sleep Deprivation and Alcohol Intoxication Using a Quantitative Model of Work-Related Fatigue*, 5(2) Sleep Research Online 67 (2003)

Sleep Research Online 5(2): 67-75, 2003
http://www.sro.org/2003/Fletcher/67/

1096-214X

Prediction of Performance during Sleep Deprivation and Alcohol Intoxication using a Quantitative Model of Work-Related Fatigue

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Shift work and particularly night work can cause fatigue with subsequent negative impacts on health, sleep, and alertness. To facilitate better management of work-related fatigue, we have developed, optimized and validated a computerized model that can predict changes in performance, vigilance, sleepiness, and tiredness. The present study is a laboratory-based validation that demonstrates the further utility of the model in predicting performance impairment resulting from sleep deprivation and alcohol intoxication. Twenty-two healthy volunteers (mean age=22.0 years) each completed three counter-balanced laboratory conditions: sleep deprivation, alcohol intoxication, and a placebo control condition. In each condition, subjects were woken at 0700 h and performance on a variety of tests was measured hourly from 0800 h. The tests at 0800 h were then used as a relative baseline to which all other performance data were expressed. The six measures of performance assessed were grammatical reasoning (response latency and accuracy), unpredictable tracking score, vigilance (response latency and accuracy), and simple sensory comparison score. Regression analyses indicated that the fatigue model predicted between 47 and 89% of the variance in actual performance measures. Thus, there were moderate to very strong significant relationships between work-related fatigue model predictions and neurobehavioral performance as measured under laboratory conditions.

CURRENT CLAIM: Following both sleep deprivation and alcohol intoxication, there are moderate to very strong relationships between work-related fatigue model predictions and objective neurobehavioral performance measures.

In performing shift work, particularly nightshift, many individuals experience sleep deprivation (SD) and increased fatigue (Glazner, 1991; Paley and Tepas, 1994; Luna et al., 1997). In turn, these can negatively impact on a range of factors including sleep (Åkerstedt, 1988, 1995; Åkerstedt et al., 1991; Kecklund et al., 1997), neurobehavioral performance (Tilley and Wilkinson, 1984; Gillberg et al., 1994; Dinges et al., 1997), as well as health and safety (Fossey, 1990; Tucker et al., 1996; Spurgeon et al., 1997).

The Relative Effects of Sleep Deprivation and Alcohol on Performance

The relative performance impairment associated with SD has been compared qualitatively to impairment due to alcohol intoxication (Peeke et al., 1980; Krull et al., 1993; Roehrs et al., 1994). The observed declines in performance with either SD or alcohol intoxication are potentially dangerous and contribute to an increased risk of accidents and incidents at work (e.g., Gold et al., 1992; Smith et al., 1994; Dinges, 1995; Smith et al., 1998). Furthermore, previous research has quantitatively compared the levels of performance impairment associated with SD and alcohol intoxication and shown that the SD and fatigue associated with common shift schedules can produce impairment greater than what would be acceptable if it were due to alcohol intoxication (Dawson and Reid, 1997; Lamond and Dawson, 1999; Williamson and Feyer, 2000).

The specific changes observed in performance following SD include significant impairments to hand-eye coordination, decision making, memory, cognition, visual search performance, response speed, and response accuracy (Linde and Bergstrom, 1992; Fiorica et al., 1968; Babkoff et al., 1988). In addition to cognitive factors, affective components of behavior, such as motivation and mood, are also adversely affected with increasing duration of SD (Babkoff et al., 1988).

With moderate levels of both SD and alcohol intoxication, there is mild impairment on performance tasks, decreased alertness, and reduction in amplitude of EEG components (Goldberg, 1966; Wallgren and Barry, 1970; Naitoh et al., 1971; Kopell et al., 1972; Johnson and Naitoh, 1974). However, there are some differences between the autonomic effects of SD and alcohol intoxication. For example, alcohol increases heart rate but SD appears to have little or no effect (Koller et al., 1966). There are also differences in affect, with alcohol decreasing (Greenberg and Carpenter, 1956) and SD-increasing indicators of anxiety (Hord et al., 1975).

Given the evidence above that the general neurobehavioral impairments due to SD and alcohol are quantitatively similar, it is paradoxical that fatigue-related performance impairment has not been subject to similar levels of regulatory intervention as alcohol intoxication. Despite the dangers posed by work-related fatigue, few organizations or policy makers currently attempt to manage workplace fatigue in any systematic or quantitative manner. It thus seems appropriate to extend the scope of our previous modeling work to equate the impairment associated with SD and alcohol intoxication with work-related fatigue. If fatigue, sleep deprivation and alcohol intoxication

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can be compared quantitatively, then we can make more global predictions of impairment based on any one of these measures. Furthermore, being able to present work-related fatigue impairment as a function of SD and alcohol intoxication may improve our understanding of the relative risks associated with fatigue.

In this paper, we present further validations of an applied modeling approach that could be a valuable tool to improve shift work management. The model enables the quantification, comparison and prediction of work-related fatigue, which can be defined as fatigue associated with hours-of-work.

Theoretical Considerations of Quantitative Modeling of Shift Work and Fatigue

The current model, as applied in this paper, is based around a number of core components of fatigue, and predicts the work-related fatigue associated with actual or potential work rosters. Specifically, these components are the duration and timing of work and break periods, the prior work history, and the limitations of recovery sleep in humans. The development, basic validation and optimization of this model have been reported in detail in two previous publications from our group (Dawson and Fletcher, 2001; Fletcher and Dawson, 2001). However, the basic components of the model as used in the current validation study are briefly summarized.

At the broadest level, the model views hours-of-work as a time-varying function, with individuals existing in one of two states (where individuals are either working or not). From this perspective, the fatigue experienced by an individual at any specific time is a balance between two competing forces, that is those producing fatigue and those reversing the effects of fatigue, leading to recovery. Fatigue and recovery are likely to increase as a function of the duration of the work and non-work periods respectively, but are also dependent on the amounts and timing of wake (or sleep) periods in the previous week. For the purposes of our model, the duration, circadian timing, and recency of work periods are considered as fatiguing forces. Conversely, the duration, circadian timing, and recency of non-work periods are considered as forces of recovery.

Duration and Timing of Work Periods

Previous research has demonstrated that fatigue increases as a function of hours of prior wakefulness (Borbély, 1982; Daan et al., 1984), with a complex relationship in which there are significant linear (hours of prior wakefulness) and sinusoidal (circadian) components (Borbély, 1982; Folkard and Åkerstedt, 1991). On the basis of previously published literature (for example, Czeisler et al., 1980a; Zulley and Wever, 1982; Johnson et al., 1992), the model assumes that the circadian component of fatigue maps closely to the circadian core temperature rhythm, with a period of 24 hours and an arbitrary amplitude of 1.0 unit. Furthermore, fatigue accumulates sinusoidally during wakefulness at a maximum rate of 2.0 units per hour at 0500 h and a minimum value of 1.0 unit per hour at 1700 h, with proportional steps at each hour of the day.

In our model, the fatigue value of a work period therefore varies as a function of the duration (Rosa et al., 1989; Folkard, 1997) and circadian timing (Folkard and Åkerstedt, 1991; Folkard, 1997) of the work period. The increase in fatigue across a work period is therefore not linear but also dependent on the time of day that the work is occurring, with more fatigue accumulating when working during the subjective night than during the subjective day. Similarly, as the duration and quality of sleep (Czeisler et al., 1980a; Zulley et al., 1981; Strogatz, 1986; Monk, 1987) show a strong circadian component, the recovery value of non-work periods are also likely to vary as a function of their duration and timing. For example, the recovery value of a 12-hour break from work during subjective night is likely to be greater than the same length break taken during subjective day.

The amount of sleep that is predicted to occur within a specific recovery period is based on a statistical distribution of sleep, using sleep propensity curves derived from free-run and forced-desynchrony protocols (see for example, Czeisler et al., 1980a; Czeisler et al., 1980b). Given a specific work/non-work pattern, the amount of sleep achieved can be predicted with surprising accuracy. However, if sleep does not occur across a period in which it is likely to occur, then the actual work-related fatigue experienced by an individual would be higher than that predicted by our model.

Recency of Shifts

The model places a higher weighting on more recent work (or non-work) periods in determining the fatigue (or recovery) level than those that occurred further back in time. The model has a linear decay from a peak weighting value of 1 for the most recent hour to a value of 0 after seven days (or 168 hours). That is, over the period of a week, the value of work or non-work periods reduces linearly, and periods that occurred more than seven days prior do not contribute at all to the work-related fatigue score.

Saturation

The model also incorporates a saturation function that limits the total value of recovery that can be accumulated at any time. In practice, this saturation function prevents recovery from being 'stored' beyond full recovery. That is, individuals can only recover from fatigue that has been accumulated and cannot accrue recovery to offset against future fatigue. The saturation of recovery reflects the fact that sleep durations are finite, with individuals experiencing difficulty in extending sleep beyond 10-11 hours in length, irrespective of the amount of prior wakefulness (reviewed in Strogatz, 1986).

Fatigue Score

Given that the fatigue level of an individual can be viewed as the sum of the fatigue and recovery functions, it is possible to calculate the relative fatigue level for an individual on the basis of the shift history of work and non-work periods. By recording only an individual's hours-of-work, we are thus able to determine the work-related fatigue level at any particular point in time.

By creating a stationary output function for the standard working week, a benchmarking approach is used to compare work-related fatigue scores produced across other shift schedules. We operationally define standard fatigue scores (measured in arbitrary units) as those representing up to 100% of the maximum produced for a standard work week (0-40 units). Moderate fatigue scores represent a range between 40-80 units (100 to 200% of the maximum produced for a standard work week) and high fatigue scores (greater than 80 units) are 200% or more of the maximum produced for a standard work week. In the same way that the effects of fatigue on performance likely have a non-linear relationship, it is assumed that fatigue scores do not progress in a linear fashion. For example, a score of 80 most likely does not represent double the fatigue level experienced at a score of 40.

Model Validations

Our previous validations of the work-related fatigue model suggest that the outputs accurately reflect changes in measures such as objective performance, vigilance, objective and subjective sleepiness, and tiredness (Dawson and Fletcher, 2001; Fletcher and Dawson, 2001). However, a useful extension of such an approach is being able to equate the relative impairment observed in such measures with impairment due to specific levels of fatigue. Furthermore, it would also be useful to compare the relative impairment due to fatigue with impairment from other sources such as alcohol intoxication. Therefore, the aim of the present study was to assess and further validate the work-related fatigue model against performance impairment produced by sleep deprivation and alcohol intoxication in laboratory trials. In addition, this will allow predictions of performance impairment (due to the influences of either sleep deprivation or alcohol intoxication) to be made from calculated work-related fatigue scores.

METHODS

Subjects

Data for twenty-two healthy university students with a mean age of 22.0 years (SEM±0.58) were included in this study. The performance data for these subjects were included in a previous study comparing the performance impairment of sleep deprivation and alcohol intoxication (Lamond and Dawson, 1999). Subjects were screened for good general health and good sleep status prior to the study. Only social drinkers were included; abstinence or excessive drinking was grounds for exclusion. Subjects with a history of sleep and/or psychiatric disorders or that were taking medications known to interact with alcohol or affect neurobehavioral performance or sleep were excluded from participation.

Procedure

Volunteers participated in an alcohol intoxication condition, placebo condition, and sleep deprivation condition, performed in a counterbalanced fashion with at least one week between conditions. Subjects were required to arrive at the laboratory at 2000 h on the night prior to each condition and they slept overnight in separate rooms in The Queen Elizabeth Hospital sleep research laboratory.

Four neurobehavioral performance tests were performed using a battery developed by Worksafe Australia. Detailed information on the specific battery of tests is given in Lamond and Dawson (1999), however they are discussed briefly hereafter. The tasks used in this study were a grammatical reasoning task (GRT) consisting of 32 presentations over 2-3 minutes, an unpredictable tracking task (TRK) of 3-minutes duration, a vigilance task (VIG) of 3.5-minutes duration, and a simple sensory comparison task (SSC) consisting of 24 stimuli presented over 1-2 minutes. Subjects were thoroughly trained on the tasks prior to commencement of each experimental condition, and all tasks were presented in counterbalanced order each time the battery was completed.

In each condition, subjects were woken at 0700 h and hourly performance testing on all four tasks was measured from 0800 h. The results of the 0800 h tests were used as a baseline reference with which all subsequent test data were compared. In the sleep deprivation condition, subjects remained awake until performance testing was completed at 1400 h on the following day. In the alcohol intoxication condition, subjects consumed an alcoholic beverage at 30-minute intervals from 0900 h until their Blood Alcohol Concentration (BAC) reached approximately 0.10%. Both alcohol intoxication and placebo condition performance testing were completed by approximately 1600 h.

Work-related Fatigue Model

To allow comparison with the performance impairments produced by alcohol intoxication and sleep deprivation, for each hour of the experiment we also modeled work-related fatigue to predict relative performance changes. The generated hourly fatigue scores were then used in the following analyses as predictors of performance.

Analyses

Performance test scores were expressed relative to the average baseline (0800 h) scores obtained before each condition. The relative scores within each interval were then averaged across all subjects to determine the mean relative performance change. The analyses used hourly intervals and/or BAC intervals of 0.01%.

Both simple linear and polynomial regressions, each modeled with an intercept through zero, were then performed for all six recorded performance measures: GRT response latency, GRT error rate, TRK score, VIG response latency, VIG % correct, and SSC % correct. Without exception, second-order polynomial regressions returned higher correlation coefficients for all variables and thus accounted for more of the variance in the data. Therefore, polynomial regression data were used in the remaining analyses. Regression equations were determined for each of these measures with both fatigue scores (FAT) and blood alcohol concentration (BAC) as the dependent measure and are reported in the results.

In order that fatigue scores could be predicted using task scores and BAC, the fatigue score and blood alcohol concentration regression equations for each of the six measures needed to be solved simultaneously. This was also done so that equivalent impairment due to alcohol intoxication could be predicted using task scores and fatigue predictions.

Finally, time-series regressions were performed between the hourly performance on each test and the predictions derived from the work-related fatigue model. Time series analysis was performed to assess whether the circadian phase of performance as predicted by the model was consistent with the actual performance phase as observed in the collected data. Statistical analysis between the regressions at a phase lag of zero and at the phase lag at maximum correlation would normally be performed to assess whether the phase differences make a statistical difference to the relationship, however this was not achievable as the duration of data collection was insufficient (i.e., <1.4 cycles).

RESULTS

Performance Measures

During the sleep deprivation condition, it was observed that performance on four of the six measures significantly decreased as hours-of-wakefulness increased. It was observed that during each hour of wakefulness, between the seventeenth and twenty-seventh hour, the mean relative decline in performance was 2.69% for GRT mean response latency, 3.36% for TRK score, 1.98% for VIG mean response latency, and 0.61% for VIG % correct (all $p<0.001$). There was no significant change in GRT error rate or SSC accuracy between seventeen to twenty-seven hours of sleep deprivation. Figures 1 and 2 show the comparative effects of alcohol intoxication and sleep deprivation on mean relative performance for all six recorded performance measures, split into two arbitrary groups. These figures also indicate the amount of sleep deprivation required to produce performance impairment comparable to that observed at BACs of 0.05 and 0.10% for each performance measure.

The decline in performance observed in the alcohol intoxication condition was due solely to the effects of alcohol, as no significant change was observed on any measure during the placebo condition. During the alcohol condition, it was observed that performance on five of the six measures significantly decreased as BAC increased. It was determined that for each 0.01% increase in BAC, the relative decline in performance was 2.37% for GRT mean response latency, 0.68% for GRT error rate, 2.68% for TRK score, 2.05% for VIG mean response latency, and 0.29% for VIG % correct (all $p<0.001$). There was no significant change in SSC accuracy across the range of BACs.

Figure 3 illustrates the associations between relative values for each of the significantly affected performance measures, and the predicted fatigue scores based on hours of wakefulness used in subsequent regression analyses. Note that performance data for GRT error rate, TRK score, and VIG error rate

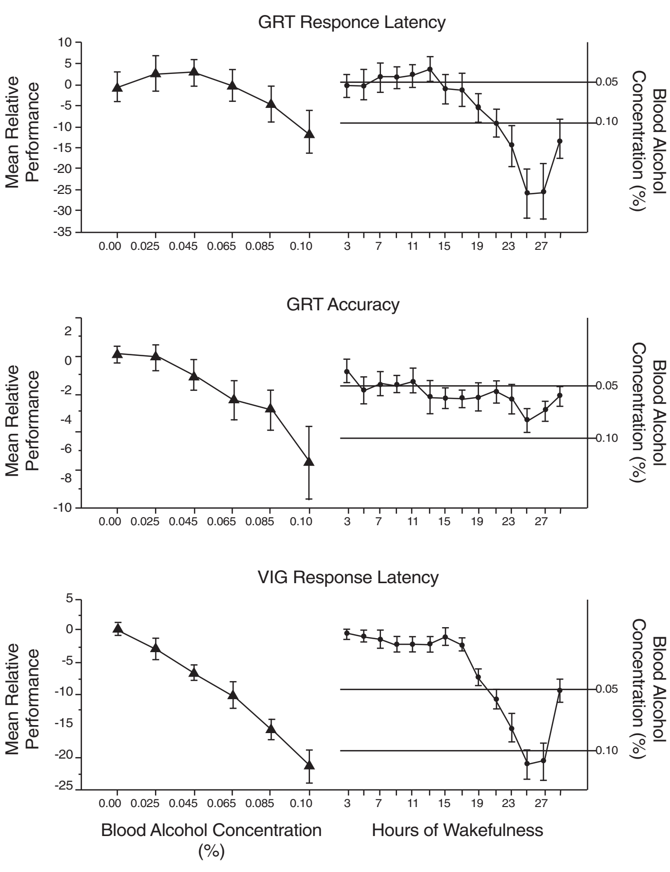

Figure 1. Mean relative performanace levels for the first group of measures on the alcohol intoxication (left) and SD condition (right). The equivalent performance decrements at 0.05% and 0.10% BAC are indicated on the right hand axis. Error bars indicate ±1 standard error of the mean (SEM).

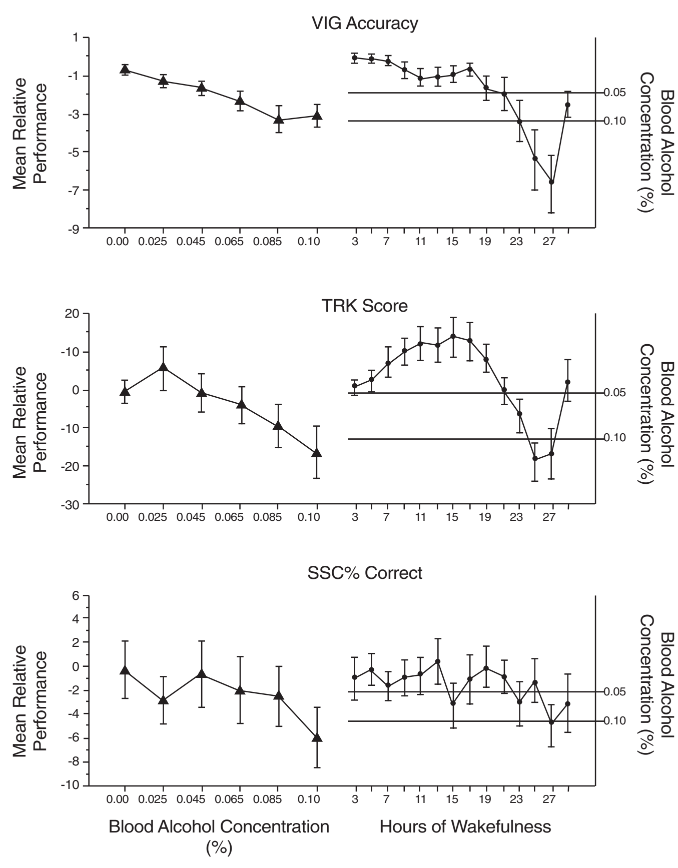

Figure 2. Mean relative performanace levels for the second group of measures on the alcohol intoxication (left) and SD condition (right). The equivalent performance decrements at 0.05% and 0.10% BAC are indicated on the right hand axis. Error bars indicate ±1 standard error of the mean (SEM).

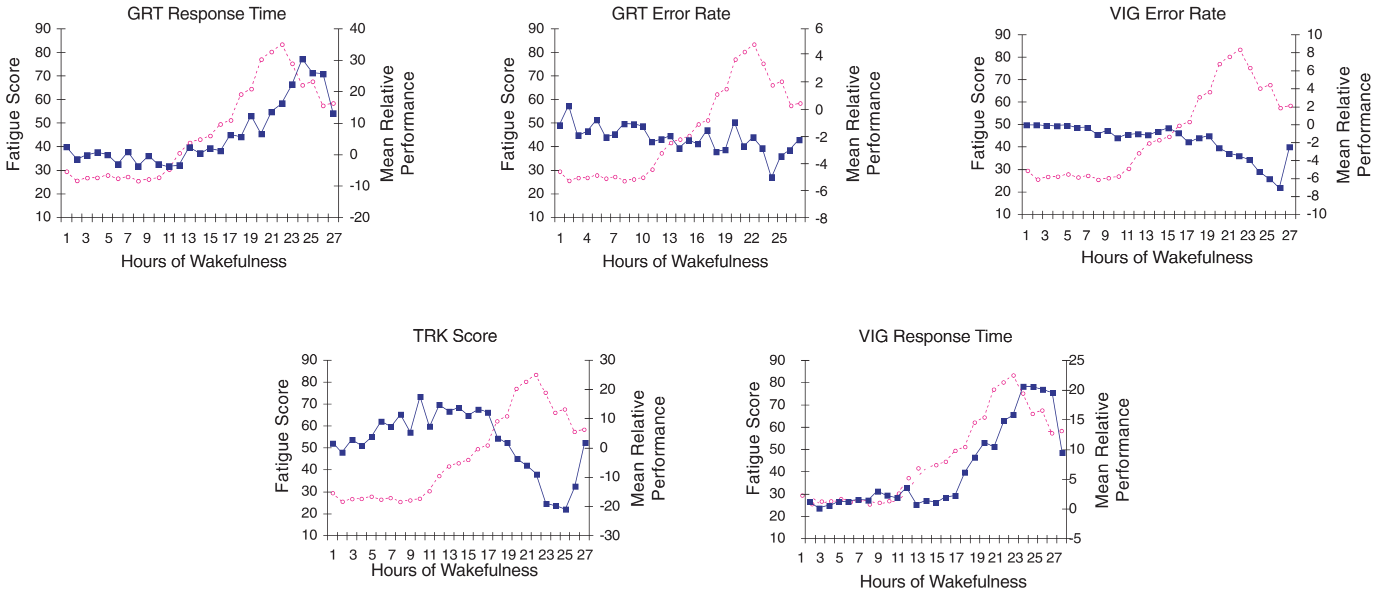

Figure 3. Predicted fatigue score (left y-axis; open circles) and mean relative performance (right y-axis; filled squares) for each of the indicated performance measures against increasing during wakefulness.

subsequently produced negative correlation coefficients (R), as predicted fatigue scores increased as relative performance values decreased, and vice-versa.

Regression Analyses

The regression equations for performance measures were determined separately, with either fatigue score or BAC as the dependent measure. Table 1 displays the regression equations for each of the six measures with fatigue score as the dependent measure. Table 2 displays the regression equations for each of the measures with BAC as the dependent measure.

The best-fit polynomial regression equations were then simultaneously solved for both fatigue score and BAC. It was found that solving polynomial equations in some cases produced a complex number (i.e., square root of a negative number) with no straightforward mathematical solution. Below, we report numerical solutions for each statistically significant performance measure where these were available from solved polynomial regressions. Table 3 displays the BAC equivalent values (rounded to 2 decimal places) of performance decline based on fatigue scores from 10 to 100.

Time-series Analysis

Time-series analyses revealed that the circadian rhythms in performance measures that were predicted by the work-related fatigue model and those observed in the collected data differed by between one and four hours. In all six measures, the work-related fatigue model predicted that the performance minimum occurred earlier than what was measured in the laboratory.

Table 5 displays the lag maximum time for each of the six measures (difference between the predicted and 'maximum fit' time relationships). The lag maximum time indicates the number of hours that the fatigue model's predictions precede the actual performance minimums.

Table 1

	Measure	Regression Equation	R^2	*p*
Y_1	GRT Mean Response	$0\text{-}0.12\ x_{FAT} + 0.01\ x_{FAT}^2$	0.68	<0.0001
Y_2	GRT Error Rate	$0\text{-}0.07\ x_{FAT} + 0.0004\ x_{FAT}^2$	0.89	<0.0001
Y_3	TRK Score	$0+0.5\ x_{FAT} - 0.008\ x_{FAT}^2$	0.47	0.0004
Y_4	VIG Mean Response	$0\text{-}0.04\ x_{FAT} + 0.003\ x_{FAT}^2$	0.84	<0.0001
Y_5	VIG % Correct	$0\text{-}0.01\ x_{FAT} - 0.0004\ x_{FAT}^2$	0.74	<0.0001
Y_6	SSC % Correct	$0\text{-}0.05\ x_{FAT} + 0.0002\ x_{FAT}^2$	0.55	<0.0001

Polynominal regression equations, R^2 and significance (*p*) values for performance measures with fatigues score (x_{FAT}) as the dependent measure.

Table 2

	Measure	Regression Equation	R^2	*p*
Y_1	GRT Mean Response	$0\text{-}165.0\ x_{BAC} + 2705.6\ x_{BAC}^2$	0.74	<0.0001
Y_2	GRT Error Rate	$0\text{-}41.1\ x_{BAC} + 221.4\ x_{BAC}^2$	0.80	0.0003
Y_3	TRK Score	$0+27.7\ x_{BAC} - 1816.2\ x_{BAC}^2$	0.76	0.0008
Y_4	VIG Mean Response	$0+110.4\ x_{BAC} + 853.9\ x_{BAC}^2$	0.98	<0.0001
Y_5	VIG % Correct	$0\text{-}53.9\ x_{BAC} + 243.0\ x_{BAC}^2$	0.96	<0.0001
Y_6	SSC % Correct	$0\text{-}101.8\ x_{BAC} + 444.2\ x_{BAC}^2$	0.27	0.21

Polynominal regression equations, R^2 and significance (*p*) values for performance measures with fatigues score (x_{BAC}) as the dependent measure.

Table 3

Fatigue Score	GRT Mean Response	GRT Error Rate	TRK Score	VIG Mean Response	VIG % Correct
10	0.06	0.02		0.00	0.00
20	0.07	0.04		0.00	0.01
30	0.08	0.07		0.01	0.01
40	0.10			0.02	0.02
50				0.04	0.03
60				0.05	0.05
70			0.06	0.07	0.07
80			0.09	0.09	
90			0.11	0.10	
100					

Blood alcohol concentrations predicted to produce equivalent decrements in performance measures to those observed at the indicated fatigued scores. Gray cells represent complex solutions (square root of negative value), nonsensical values (i.e., performance at BAC <0%) or predicted values that are outside the limits of data measurement (i.e., performance at BAC >0.11%).

Table 4

BAC (%)	GRT Mean Response	GRT Error Rate	TRK Score	VIG Mean Response	VIG % Correct
0.00				13	
0.01			62	28	25
0.02		11	63	37	39
0.03		16	64	44	48
0.04		21	66	51	55
0.05		25	68	58	61
0.06	10	28	71	64	65
0.07	20	31	74	70	69
0.08	27	33	78	76	71
0.09	33	34	81	82	73
0.10	39	33	85	88	74

Fatigue scores predicted to produce equivalent decrements in performance measures to those observed at the indicated blood alcohol concentration. Gray cells represent complex solutions (square root of negative value) or vlues that exceed the limits of data measurement (i.e., performance at fatigue score <10).

Table 5

	Lag Maximum (hrs)
GRT Mean Response	2
GRT Error Rate	1
TRK Score	3
VIG Mean Response	1
VIG % Correct	3
SSC % Correct	4

Time-series analysis results for all performance measures. Lag maximum is the time difference between a correlation at a time of zero hours, R(0) and at a time of best correlation. R(max).

DISCUSSION

The aim of this study was to further validate a model of work-related fatigue against performance measures recorded during sleep deprivation (SD) and alcohol intoxication. By knowing the impact of both SD and alcohol on performance, we were able to express the effects of sleep deprivation on performance as a fatigue score or blood alcohol equivalent. Similarly, we could express the effects of alcohol intoxication on the performance measures as a fatigue score or sleep deprivation equivalent.

The amount of variability in performance measures accounted for by fatigue scores ranged between 47 and 89%, with the strongest correlation existing between predicted fatigue and the GRT error rate. Next highest was the relationship between fatigue predictions and vigilance response latency (84% of the variance was predicted). For vigilance accuracy, 74% of the variance was accounted for by the fatigue predictions. Finally, 55% of the variance in simple sensory comparison and 47% of the variance in tracking score was accounted for by fatigue predictions. The variability accounted for by blood alcohol concentrations (BAC) was somewhat higher within the significantly affected measures, ranging between 74 and 98%. The highest correlation existed between BAC and the vigilance response latency (98%), followed by vigilance accuracy (96%), grammatical reasoning error rate (80%), tracking score (76%), and grammatical reasoning response latency (74%).

These data show that, for only one out of the five measures significantly predicted by both fatigue score and BAC, the work-related fatigue scores had a stronger relationship with the performance data than did BAC. It is therefore clear that BAC levels account for a greater proportion of the variance in the performance data than the fatigue scores. Nevertheless, predicted fatigue scores still related moderately to strongly with the measured performance measure data and supports the practicality of the model in predicting performance impairment due to SD.

In the present study, performance impairment at various fatigue scores was equated to comparable levels of impairment due to alcohol intoxication. Discussion of the effects of alcohol intoxication and sleep deprivation on performance was discussed in a previous paper from our group (Lamond and Dawson, 1999) and is therefore limited here except where specifically related to assessment of work-related fatigue. Specifically, performance decrements equivalent to those observed in the 0.05-0.10% BAC range occurred at fatigue scores between 10 and 90 points. For vigilance score, the most highly correlated measure for work-related fatigue, performance decrements equivalent to those observed in the 0.05-0.10% range occurred at fatigue scores between 60 and 90 points. From the perspective of the fatigue scores, performance decrements equivalent to those observed in the 50-80 range of fatigue scores occurred between 0.01-0.09% BAC. For vigilance response latency, the most measure with best-fit against BAC, performance decrements equivalent to those observed in the 50-80 fatigue point range occurred between 0.04-0.09% BAC.

These findings can be compared with a previous validation between outputs of the current work-related fatigue model and conditions of sleep deprivation and alcohol intoxication (data from Dawson and Reid, 1997; cited in Fletcher and Dawson, 2001). This previous validation observed changes in neurobehavioral performance, as determined by the OSPAT tracking performance assessment task, across 28 hours of sleep deprivation and alcohol intoxication up to 0.10% BAC in a separate group of volunteers to the present study. The OSPAT test determines a performance score based on changes in hand-eye co-ordination, reaction time and vigilance measures. This validation of work-related fatigue against performance predicted that a fatigue score of 80 points produced impairment on the OSPAT test equivalent to a BAC greater than 0.05%. The current validation suggest that the performance impairment observed at 80 points is equivalent to impairment measured at slightly higher BAC levels, above 0.08% on the measures that were significantly affected in this study.

It is worth noting that the predicted BAC equivalents at 80 fatigue points are interpolated from the fatigue score data predictions for three of the measures. That is, the BAC predicted to produce impairment equivalent to that observed at 80 fatigue points is actually higher than the testing limit (BAC=0.10%) of BAC for GRT mean response times, GRT error rate and VIG % correct. However, based on the actual data for TRK score and VIG response latency, the performance at 80 points is predicted to be equivalent to the performance decrement seen at around 0.08 and 0.09% respectively. Of these two measures, vigilance response correlates most strongly with the fatigue predictions. In fact, vigilance response was perhaps the most utilitarian measure of all, with very strong correlations (R^2=0.84 and 0.98 for sleep deprivation and alcohol intoxication, respectively) and the broadest range of predictive values (see Tables 3 and 4).

The variations in correlations reflect the fact that different tasks are differentially sensitive to the effects of SD and alcohol. Underlining this fact is the observation that SSC % correct was not significantly affected even at a BAC of 0.10%. Across the range of experimental conditions in this study therefore, this measure was completely insensitive to the effects of moderate alcohol intoxication. GRT latencies and error rates were significantly impaired by mild levels of SD, with a modeled fatigue score of only around 30-40 equivalent to BAC impairment around 0.07-0.10% (see Table 3). On the other hand, vigilance latency and error rates were particularly sensitive measures as reflected by a much broader spread in predictions of performance impairment. Using solved regression equations for vigilance response, it was predicted that the equivalent BAC impairment at 80 fatigue points would be approximately 0.09% BAC.

While it is clear that the relationships between performance measures and fatigue scores were moderate to very strong, this was particularly the case for vigilance score. However, the basic time series analyses that were performed indicate that the relationships could be strengthened further. This is because the outputs generated by the fatigue model predict a performance trough earlier than in the actual performance data. An explanation for this potential phase mismatch is discussed hereafter.

We know from the literature that many aspects of human performance and alertness map closely to the circadian rhythm of core body temperature (Monk et al., 1983; Folkard and Monk, 1985; Monk and Moline, 1989; Johnson et al., 1992; Monk and Carrier, 1998). Furthermore, it has also been documented that factors such as age (Monk et al., 1995; Campbell and Murphy, 1998) or sleep/wake pattern (Moore-Ede et al., 1982; Wilkinson, 1982) can have a significant impact on when core body temperature and thus performance measures will peak and trough. Therefore, it is not surprising that the performance troughs in our young adult subjects occur later than the work-related fatigue model would predict. The work-related fatigue model is constructed using generalized principles that include a predicted "normal" performance trough at 0400 to 0600 h. However, because the subject population in this study is quite young (average age of 22 years), this trough may be delayed. As shown in Table 5, the performance troughs on the six measures occur between one to four hours later than the model would predict. Whether or not this phase difference impacts significantly on the results cannot be determined, as the measurement period of the study was too short to allow statistical analysis across the entire cycle of performance. However, it is likely that the reported relationships between fatigue scores and performance measures may have been overly conservative, hence increasing the utility of the present model in normally entrained individuals, as any inherent error would underestimate the fatigue experienced by a particular work schedule.

Based on the polynomial regression between fatigue and vigilance response (R^2=0.84), a fatigue score of 80 is comparable with the impairment that would be observed in an individual with a BAC of 0.09% or greater. If an individual registered such a BAC while working or operating a motor vehicle, they would clearly not be permitted to continue. However, a significant proportion of the rosters employed in 24-hour operations produce work-related fatigue scores greater than 80 (for examples, see Dawson and Fletcher, 2001). Therefore, the same level of performance impairment that would be unacceptable if it were due to alcohol regularly occurs due to work-related fatigue. The specific impact of any roster on work-related fatigue will obviously depend on a number of factors including number of consecutive night shifts and duration of break periods (Knauth, 1998). However, as a general rule it is difficult but not impossible to avoid fatigue scores greater than 80 points when employees are required to work in 24-hour operations.

Comparisons such as those conducted in this manuscript can lead to questions like, "How tired is too tired?" in relation to work safety. Results of the present and previous studies give us some indication of what levels of fatigue should be accepted, however, in order to better answer this question we are conducting further validations of simulator and field-based shift work data against fatigue-model predictions. Finally, while focusing here on work-related fatigue, we also acknowledge the additional impacts of non-work-related fatigue on fatigue in general. That is, the impacts of individual differences in family and social arrangements, coping strategies, and employee support services or lifestyle education and training competency.

Such issues can make very significant differences to the impact of any roster on fatigue. With further validations and increasing understanding of non-work issues, models such as the one used in the present validation should provide increasing accuracy and utility in the future.

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Exhibit 29:

AM Williamson and Anne-Marie Feyer, *Moderate Sleep Deprivation Produces Impairments in Cognitive and Motor Performance Equivalent to Legally Prescribed Levels of Alcohol Intoxication*, 57 Occupational Envtl. Med. 649 (2000)

Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication

A M Williamson, Anne-Marie Feyer

Abstract

***Objectives*—To compare the relative effects on performance of sleep deprivation and alcohol.**

***Methods*—Performance effects were studied in the same subjects over a period of 28 hours of sleep deprivation and after measured doses of alcohol up to about 0.1% blood alcohol concentration (BAC). There were 39 subjects, 30 employees from the transport industry and nine from the army.**

***Results*—After 17–19 hours without sleep, corresponding to 2230 and 0100, performance on some tests was equivalent or worse than that at a BAC of 0.05%. Response speeds were up to 50% slower for some tests and accuracy measures were significantly poorer than at this level of alcohol. After longer periods without sleep, performance reached levels equivalent to the maximum alcohol dose given to subjects (BAC of 0.1%).**

***Conclusions*—These findings reinforce the evidence that the fatigue of sleep deprivation is an important factor likely to compromise performance of speed and accuracy of the kind needed for safety on the road and in other industrial settings.**

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Keywords: sleep deprivation; performance; alcohol

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The implications of fatigue for safe performance are well recognised particularly in road safety, but in other settings as well. Fatigue is most likely to occur when rest is reduced such as when working long or irregular hours, doing shift and night work, or due to family responsibilities or lifestyle choices. Effects of fatigue are thought to play a part in between 16% and 60% of road accidents[1 2] and in the United States were estimated to cost in the vicinity of $50 billion.[3]

Recently authors have argued that until now society has simply accepted the hazards of fatigue despite evidence of increased risk to health and safety.[4 5] This has led to calls for better information on the extent and consequences of the effects of fatigue on performance.[6] The problem, in practice, is at what level of fatigue does performance become a problem? In setting any safety standard for the fatigue caused by sleep deprivation, the sort of information needed is a comparison of performance after a known number of hours spent awake with that caused by some other agent that decreases performance.

Alcohol effects serve as a good model for an acceptable standard for safe performance. Alcohol effects have been measured and standardised by setting limits on alcohol consumption based on their predicted effects on driving performance.[7] Many countries have set limits for alcohol levels while driving which are based on laboratory, simulator, and on road measures of speed and accuracy of performance.[8] These standards provide a benchmark for performance deficits caused by injury, illness, or in this case, the fatigue of sleep deprivation. By comparing the change in performance due to alcohol consumption at concentrations widely agreed to be hazardous (0.05% blood alcohol concentration (BAC))[8] with the same behaviour after sleep deprivation, it should be possible to assess the amount of sleep deprivation at which equivalent deficits occur. This is the aim of our study. An earlier study[9] used a similar study design but looked at effects on only a single test (eye-hand coordination). Single tests which are an amalgamation of functions and simple in terms of effort may not show sufficient information for setting standards in a range of work settings. The current study looked at effects on a range of performance tests including tasks involving cognitive and motor speed, accuracy, coordination, and attention.

Method

SUBJECTS

Thirty nine subjects participated in this study. Thirty seven were male and two were female. Table 1 shows demographic characteristics for the sample. Most subjects were in the 30–49 age group (59%) and were living with a partner (77%). Most subjects had only 10 years of education or less (60%). Subjects were volunteers from a large road transport company (30 subjects) and the transport corps of the Australian army (nine subjects). In both cases, all subjects were volunteers from the drivers and administration staff available at the time. They were allowed paid work time to participate in the study. Subjects were given information about the study and asked to participate. All signed a consent form before participating. There was no attempt at selecting participants on any basis other than that they worked for the respective organisations and were willing to participate after learning about the study.

Table 1 Demographic characteristics of sample and details of uses of social drugs

Characteristics	*%*
Age (y):	
<30	35.9
30–49	59.0
>50	5.1
Marital status:	
Married or cohabiting	76.9
Single	23.1
Formal education:	
⩽10 y	60.5
11–12 y	15.8
Technical college	13.2
University	10.5
Smoking history:	
Non-smokers	41.0
Ex-smokers	25.6
Current smokers	33.3
Smokes/day (mean (SD))	21.46 (7.59)
Caffeinated beverages:	
Consuming	92.3
Drinks/day (mean (SD))	4.29 (2.01)
Frequency of alcohol use:	
Rarely	10.3
Weekly	41.0
2–3 Times weekly	43.6
Daily	5.1
Drinks/occasion:	
⩽3	53.8
⩾4	46.2

MEASURES

Several performance tests were used, as described below. All tests were well established and had been used in many previously reported studies. They were chosen on the basis that they had shown sensitivity to the effects of fatigue. All tests were administered on a computer screen with a standard mouse and a keypad.

Mackworth clock

A passive vigilance test involving very low cognitive demand.

Simple reaction time

A simple response speed test.

Tracking

A low level, hand-eye coordination task with simple cognitive demands.

Dual task

A divided attention task combining the simple reaction time and tracking tests

Symbol digit test

A perceptual coding test

Spatial memory search

Memory test for a sequence of targets, with moderate complex cognitive demands and low level hand-eye coordination.

Memory and search test

A memory test with moderately complex cognitive demands and low level hand-eye coordination.

Grammatical reasoning

A logical reasoning test involving complex cognitive demands and low level hand-eye coordination.

At the beginning and end of each test session, subjects were asked to estimate their own fatigue by moving a cursor along a line on the screen corresponding to their current state of tiredness. A demographic questionnaire covering age, education level, health, recent work, and recent sleep history was administered to all subjects before the first test session. This included the Epworth sleepiness scale[10 11] and three global questions on problems getting to sleep, staying asleep, and staying awake. Risk of sleep apnoea was defined as the co-occurrence of loud snoring, excessive nocturnal movement, cessation of breathing, difficulty maintaining sleep, and difficulty staying awake.[12] None of the subjects showed evidence of sleep apnoea based on their questionnaire results. Before every test day, subjects were also asked about their sleep during the previous night and their food and drug intake since waking.

PROCEDURES

All testing was conducted in the laboratory. The study used a cross over randomised control design (table 2). This meant that all subjects participated in both alcohol consumption and sleep deprivation and the order of testing was counterbalanced so that half did the alcohol consumption first and the other half the sleep deprivation first. Subjects were allocated alternately to each order of testing as they entered the study. To reduce carry over effects from one condition to the other, subjects were allowed a long break in the afternoon after testing and had an overnight rest at a local motel between tests.

Subjects were tested in groups of two to six. On the afternoon before testing began, subjects spent about 4 hours doing three practice sessions for all tests. They were then sent to a local motel for an overnight rest. On the next morning testing started about 2 hours after waking, at about 0800, for either the sleep deprivation or alcohol consumption. This was alternated for each group of subjects. The alcohol consumption involved baseline performance testing as soon as subjects arrived in the laboratory, followed by doses of alcohol at hourly intervals, with performance tests 30 minutes after each dose. Alcohol was given in four consecutive doses designed to achieve BACs of 0.025, 0.05, 0.075, 0.1%. Doses were adjusted according to percentage body fat, weight, sex, and age.[13] Alcohol was given in the form of the subject's preferred variety of spirits with their preferred mixer. Alcohol measures

Table 2 Overview of the study design showing alcohol followed by the sleep deprivation

Time	*0800*	*0930*	*1030*	*1130*	*1230*	*1500*	*1700*	*1900*	*2100*	*2300*	*0100*	*0300*	*0500*	*0700*	*0900*
Day 1: practice from 1400						T	T								
Day 2: alcohol	T	T*	T*	T*	T										
Day 3: sleep deprivation condition	T	T*	T*	T*	T	T	T	T	T	T	T	T	T	T	T

T=performance test; T*=short version of test.
For half of the subjects the order of alcohol and sleep deprivation was reversed.

(blood-breath equivalents) were taken with a breathlyser (Drager Alcotest 7110) immediately before and after each test session and then hourly until the subjects' alcohol concentrations were below 0.05%. The subjects were then allowed to leave the test centre.

The sleep deprivation involved the same sequence of testing as for the alcohol consumption, with tests every hour from baseline to the 5th hour, as in the alcohol consumption, then every 2nd hour for the next 20 hours. The last test occurred 28 hours after waking. There were five performance test sessions in all for the alcohol consumption and 15 for the sleep deprivation. The order of tests was randomised within each test session. Most tests were used in all sessions: however, three tests (grammatical reasoning, spatial memory search, and memory and search task) were dropped from the second, third, and fourth test sessions to allow time for alcohol to be drunk and absorbed. This procedure was also used for the sleep deprivation so that direct comparisons could be made between the conditions.

STATISTICAL ANALYSIS

For statistical analysis, for each subject the BACs recorded at the start and end of each of the five test sessions were averaged to produce a single value for each test session. These average BACs and the associated performance test measures were plotted separately against test session for each subject. Due to individual differences in absorption of alcohol, the observed BACs were not always at the anticipated level at each test session. This meant that the time at which the exact BACs of 0.025%, 0.05%, 0.075%, and 0.1% were reached had to be interpolated from the graph for each subject. These times were then identified on the graph of performance test measures against test session and the corresponding test scores could then be interpolated for each subject. By this method it was possible to estimate the performance test score corresponding to each concentration of alcohol for each subject. These concentrations were then averaged across subjects to show change in performance with each alcohol dose.

Performances at the BACs of 0.05% and 0.1% were then compared with performance across sleep deprivation test sessions 8–13 (at times 1900–0500) for each subject. This time window was chosen for the sleep deprivation condition before the data were collected because this period was most likely to produce effects of fatigue as it covered the longest periods of sleep deprivation and covered the period of the major circadian trough. This decision was reinforced when the sleep deprivation and performance relation was plotted after data collection, as this period also showed the clearest linear trend across test sessions for all measures. For this analysis, time was treated as a continuously increasing quantity across midnight, for example, 20 hours of sleep deprivation occurred at 0200, as the waking time had been about 0600. Over this time window, the sessions between which performance under the sleep deprivation first became worse than the performance found at BACs of 0.05% and 0.1% were noted for each subject. With interpolation, the time since waking associated with performance equivalent to that at the two alcohol concentrations were then identified for each subject. The scores for time since waking were then averaged across subjects for each performance measure.

Table 3 Amount and quality of sleep the night before alcohol and sleep deprivation

	Before alcohol Mean (SD)	*Before sleep deprivation Mean (SD)*
Amount of sleep	7.5 (2.4)	7.2 (1.0)
Rated quality of sleep	71.5 (25.0)	58.7 (24.9)
Ratings of freshness at waking	72.7 (19.8)	65.2 (22.6)

Not all subjects contributed to the time since waking scores for each measure as not all subjects showed a deterioration in performance over this time window for all performance tests. Only data from subjects who showed a change from better than the BACs of 0.05% and 0.1% to worse than these criterion concentrations over the 1900 to 0500 window were included in the averages for each test. The number of subjects contributing to each hour of wakefulness equivalent to the BACs therefore reflects the percentage of subjects who showed significant deterioration in performance over the selected time window.

Results

Subjects were reasonably well rested after a mean of 7.54 and 7.16 hours overnight sleep immediately before each test condition, for alcohol comsumption and sleep deprivation respectively (table 3). Although sleep quality was rated as significantly lower before sleep deprivation, the amount of sleep and ratings of feeling fresh after waking did not differ between the conditions, indicating that subjects were not partially sleep deprived before either test condition.

As expected, increasing concentrations of alcohol produced significant reductions in performance for most tests and measures. Table 4 shows the results of the estimated change in performance due to varying amounts of alcohol compared with baseline, no alcohol. The results show that the extent of loss of function varies between tests although there were consistent effects within different types of measures. At a BAC of 0.05% for example, response speed decreased by around 8%–15% for reaction time, dual task, Mackworth vigilance, and symbol digit tests corresponding to a slowing of around 45, 66, 136, and 182 ms respectively. Hand-eye coordination measures showed a similar overall decrement of around 10% at this BAC. Measures of overall test accuracy also showed significant decrements due to alcohol, especially the number of missed signals in the reaction time test, which increased by 200%, and the number of false alarm responses in the Mackworth test, which were more than 50% higher at a BAC of 0.05%. The number of correct responses in the Mackworth test and length of the recalled series in the spatial memory task also both

Table 4 Interpolated performance estimates at baseline and with blood alcohol (BAC) at certain concentrations

Test	Measure	Baseline 0.00	BAC (%) 0.05	0.1
Reaction time	Speed (ms)	489	534	566
	Accuracy (misses)	0.36	1.17	2.81
Dual task	Speed (ms)	662	725	792
	Hand-eye coordination difficulty level	50.59	45.43	23.69
Tracking	Hand-eye coordination difficulty level	47.76	44.35	23.39
Mackworth	Speed (ms)	958	1094	1361
	Accuracy (targets detected (n))	12.64	10.91	7.76
	Accuracy (false alarms)	1.05	1.63	4.48
Symbol digit	Speed (ms)	2233	2415	2656
	Speed (targets inspected (n))	40.11	37.32	32.74
	Accuracy (correct (%))	99.00	97.83	94.52
Grammatical reasoning*	Speed (ms)	4286	4135	3945
	Accuracy (correct (n))	23.19	21.89	20.05
Memory and search*	Speed (ms)—2 targets	12222	12399	12500
	Speed (ms)—6 targets	20853	20302	19555
	Accuracy (correct (n))—2 targets	5.59	5.31	5.01
	Accuracy (correct (n))—6 targets	5.05	4.66	4.21
Spatial memory*	Length of recalled series	5.34	4.65	3.73
Tiredness	Rating	17.84	31.63	44.83

*Performance estimates based on only the first and last test occasion.

decreased by about 13% at a BAC of 0.05%. Subjective ratings of tiredness also showed a significant linear decrement of 77% by a BAC of 0.05%. Two tests, grammatical reasoning and memory and search tests showed very little decrease in performance at a BAC of 0.05%.

At a BAC of 0.1% performance was poorer for all measures for all tests and some measures showed more than twice the decrement at a BAC of 0.05%. The biggest changes were seen for the accuracy measures, number of misses in the reaction time test, which was nearly seven times poorer at a BAC of 0.1% than at baseline, and the number of false alarms for the Mackworth vigilance test, which increased to three times the level at baseline. Hand-eye coordination in both tracking and dual tasks also showed a much larger decrement than other tests, with a 50% deterioration at this BAC. Response speed for the Mackworth test also deteriorated more than might be expected and showed 42% slowing compared with baseline. By comparison, the other measures—response time for the simple reaction time, dual task and symbol digit tests, the spatial memory test, and subjective ratings of fatigue—all showed around twice as much deterioration at a BAC of 0.1% than 0.05%. Similarly, the higher cognitive tests, logical reasoning, and memory and search also showed around twice the level of deterioration at this BAC, but the level of deterioration was still quite small (around 10%), even at this higher level of alcohol.

These results show that alcohol does not exert universal effects on all functions and the pattern of effects also differs between them.

Sleep deprivation also produced decrements in both performance and self rated alertness. As shown in table 5, sleep deprivation showed effects on a similar range of tests as did alcohol. At the beginning of the analysed time window (1900) performance for most tests was very similar to performance during the first session of the sleep deprivation test day. Over the time window, however, performance decrements occurred with increasing sleep deprivation for both speed and accuracy measures of the reaction time, dual task, tracking, and Mackworth tests and for the length of the recalled series for the spatial memory test. For example, between around 1900 and 0500 (corresponding to

Table 5 Interpolated performance estimates as a function of time of day (hours since waking where average waking time was 0544) during the selected sleep deprivation time window

Test	Measure	First sleep test session 0800 (2.27)	Start of analysed window 1900 (13.27)	Time of day (hours since waking) 1944 (14.00)	2344 (18.00)	2744/03 44 (22.00)
Reaction time	Speed (ms)	494	495	497	521	540
	Accuracy (misses)	0.69	1.08	0.98	1.67	3.10
Dual task	Speed (ms)	618	617	627	709	775
	Hand-eye coordination difficulty level	48.84	48.31	49.11	46.62	33.37
Tracking	Hand-eye coordination difficulty level	44.07	49.52	47.66	40.83	36.70
Mackworth	Speed (ms)	1020	964	1010	1225	1511
	Accuracy (targets detected (n))	12.77	12.00	11.89	9.86	7.04
	Accuracy (false alarms)	2.15	1.28	1.48	2.85	4.24
Symbol digit	Speed (ms)	2289	2245	2282	2430	2577
	Speed (targets inspected (n))	38.49	40.05	39.30	36.90	34.30
	Accuracy (correct (%))	98.05	98.32	98.29	98.37	97.41
Grammatical reasoning	Speed (ms)	4413	4054	4128	4255	4182
	Accuracy (correct (n))	21.62	23.59	23.13	22.76	22.46
Memory and search	Speed (ms)—2 targets	11988	11336	11620	12439	12581
	Speed (ms)—6 targets	22423	20729	20787	21460	21101
	Accuracy (correct (n))—2 targets	5.54	5.65	5.57	5.37	5.35
	Accuracy (correct (n))—6 targets	5.08	5.16	5.14	5.12	4.80
Spatial memory	Length of recalled series	5.25	5.15	5.14	4.87	4.27
Tiredness	Rating	19.87	38.74	40.52	58.62	75.47

Performance during the first test session of the sleep deprivation is included for comparison with the start of the selected window.

Table 6 Equating the effects of sleep deprivation and alcohol consumption

Test and measure	Hours (decimal) of wakefulness equivalent to BAC concentrations: BAC 0.05% Mean	95% CI	%*	BAC 0.1% Mean	95% CI	%*
Reaction time task:						
Speed (ms)	18.04	17.12 to 18.96	76	18.71	17.56 to 19.86	64
Accuracy (misses)	17.31	16.51 to 18.11	42	17.74	16.51 to 18.97	45
Dual task:						
Speed (ms)	17.73	16.75 to 18.71	84	19.65	18.58 to 20.77	67
Hand-eye coordination (level of difficulty)	18.43	17.41 to 19.45	79	19.42	18.40 to 20.44	58
Tracking task:						
Hand-eye coordination (level of difficulty)	18.25	17.37 to 19.13	74	19.01	18.91 to 19.97	61
Mackworth clock vigilance:						
Speed (ms)	17.08	16.20 to 17.96	82	18.10	16.85 to 19.35	58
Accuracy (misses)	17.64	16.72 to 18.56	68	18.80	17.93 to 19.67	76
Symbol digit task:						
Speed (ms)	18.55	17.43 to 19.67	50	18.91	17.92 to 19.90	48
Speed (symbols inspected (n))	18.52	17.46 to 19.58	57	18.64	17.65 to 19.63	79
Accuracy (correct (%))	16.91	15.72 to 18.10	41	18.39	17.01 to 19.77	42
Spatial memory task:						
Accuracy (length of recalled sequence)	18.05	17.09 to 19.01	86	17.88	16.92 to 18.84	64

*Numerator=number of subjects contributing data; denominator=number of subjects whose range of BAC incorporated 0.05% (n=37 or 38) or 0.1% (n=33).
Amount of sleep deprivation required to produce performance decrements equivalent to varying concentrations of blood alcohol (BAC), and the time of day at which the equivalence occurred in this study.

about 13–23 h sleep deprivation), reaction speed decreased by 57% for the Mackworth test, 9% for reaction time, 27% for dual task and 15% for symbol digit tests. Hand-eye coordination decreased by between 31% for the tracking component of the dual task and 26% for the tracking task alone. Accuracy also decreased markedly with sleep deprivation. The number of missed signals increased by more than 40% for the Mackworth test, by 187% for the reaction time test, and the number of false alarms increased by 200% for the Mackworth test. The symbol digit test only showed decrements for the speed measures but not the accuracy measure. The grammatical reasoning and memory and search tasks showed only relatively small decreases of around 5%–10% with increasing sleep loss for any measures.

The levels of sleep deprivation estimated to produce decrements in performance equivalent to varying concentrations of alcohol are shown for each performance measure in table 6. The results indicate that on average, 0.05% equivalence occurred after being awake for around 16.91 to 18.55 hours, placing the time of the effect in this study to between 2238 and 0017. At a BAC of 0.1%, equivalence occurred after between 17.74 and 19.65 hours of wakefulness which falls in the late evening to early hours of the morning, corresponding in this study to between 2328 and 0123. Measures within and between tests were affected at very similar levels of sleep deprivation. The performance test that seemed to be affected first was the passive vigilance test, the Mackworth clock test, where equivalence to a BAC of 0.05% occurred after just over 17 hours of wakefulness for all measures. The accuracy measure of the symbol digit test reached levels equivalent to 0.05% alcohol earlier than any other measure for any test, but equivalence occurred considerably later for the other symbol digit test measures. The likelihood of missing targets in the reaction time test was also affected by sleep deprivation slightly earlier than other tests equivalent to a BAC of 0.05% as it also occurred at just over 17 hours of wakefulness. The two tests that showed little change with increasing sleep loss, grammatical reasoning and memory and search tasks, were not included in this analysis as alcohol equivalences are likely to be misleading.

Table 6 shows that the percentage of subjects showing poorer performance than a BAC of 0.05% and 0.1% across the session 8–13 window varied considerably between tests. More than three quarters of subjects showed deterioration in performance to become poorer than the BAC of 0.05% for speed measures in the simple reaction time, dual task, and Mackworth clock vigilance tests, and in the accuracy of the spatial memory search test. By contrast, for the accuracy measures of the simple reaction time and symbol digit tasks only around 40% of subjects showed performance decrements sufficient to be at or poorer than the BAC of 0.05%. As might be expected, for most tests, a smaller percentage of subjects showed performance levels equivalent to a BAC of 0.1%. Nevertheless for most tests, more than half of the subjects showed deterioration in performance equivalent to a BAC of 0.1%. Fewer subjects reached a BAC of 0.1% for the accuracy measures of reaction time and symbol digit tests, as was found for 0.05% equivalence. For a few measures, more subjects reached equivalence to a BAC of 0.1% than 0.05%, notably, accuracy on the Mackworth test, and the number of symbols inspected in the symbol digit test. This finding is most likely because these measures had a performance ceiling and many subjects remained at the ceiling, even at a BAC of 0.05%, and only showed a performance decrement between the BACs of 0.05% and 0.1%.

Discussion

This study shows that commonly experienced levels of sleep deprivation depressed performance to a level equivalent to that produced by alcohol intoxication of at least a BAC of 0.05%. At the end of periods of waking of 17–19 hours, performance levels were low enough to be accepted in many countries as incompatible with safe driving. The earliest effects were seen for the Mackworth clock test and the latest for the dual task, although there was relatively little variation across tests. Longer periods of sleep deprivation were equivalent to higher alcohol doses for all tests except the grammatical reasoning and memory and search tasks.

Equivalence with the BAC of 0.05% was also very similar within tests. Both parts of the dual task, either when tested alone, or in combination, showed equivalence at between 17 and 19 hours of sleep loss corresponding in this study to between 2240 and 0050. For all measures of the Mackworth clock test, equivalence occurred after around 17 hours of sleep loss and for the symbol digit test after about 17–19 hours without sleep.

These results show that impairments in performance which have been judged as the legal limit for driving safely may start to occur as early as 17 hours after waking and around 18 hours on average after waking. These results confirm earlier work on a single task.[9] It is important that these periods of wakefulness also correspond to the normal waking day for most people. In the community a 16–17 hour period of wakefulness would be regarded as normal, with bedtime typically occurring in the mid to late evening depending on the time of rising. It could be argued, therefore, that this common pattern of waking and sleeping plays a major part in ensuring safety. If the period of wakefulness is extended beyond the usual 16–17 hours, performance is likely to be impaired sufficiently to represent a considerably greater risk of injury. Driving home after a long work day, for example, may put you at increased risk of an accident. Drivers who have been awake for more than 17–18 hours are likely to be significantly slower at reacting and will be increasingly likely to miss information as the period of sleep loss increases even further.

This study looked at effects of sleep deprivation only under day worker conditions where subjects were rested after a reasonable number of hours sleep the night before. Although most people follow this sleep-waking regime, work schedules and lifestyle demands increasingly require people to extend their waking period for longer than 18 hours, shortening their sleeping period as a consequence, and to do so repeatedly over days, weeks, or even months. The effects of such chronic partial sleep deprivation have not been considered by this study although these findings and a recent review of the literature[14] suggest that partial sleep deprivation may present very serious risk for safe performance.

Although this study has not directly considered the role of circadian effects, it is known that they interact with deficits in performance from continuous or partial sleep deprivation.[15] This study was designed to only look at the effects of sleep loss over a night without sleep after a day awake as this is the form that sleep loss often takes. This meant, however that the period of maximum sleep loss coincided with the time that circadian influences should have been greatest. As a result, performance deficits may have been higher for measures that were vulnerable to circadian influences so enhancing the apparent effects of sleep loss. Further research is needed to clarify the relative effects of sleep deprivation and circadian influences and to measure them against the alcohol consumption benchmark. It is notable, however, that the deficits from sleep deprivation found here equivalent to a BAC of 0.05%, occurred between 2200 and 0000, which is well ahead of the time at which the circadian trough occurs.[15 16] This suggests that sleep deprivation and not circadian influences causes serious concern about decrements in performance, although our results show the additional deterioration in performance due to circadian effects.

The overall implications of the results of this study are clear. They show that the effects on performance of moderate periods of being awake cannot be discounted. Sleep is needed after the end of a day if adverse effects on performance are to be avoided. Most importantly, this study has allowed interpretation of these effects on performance in terms of an accepted standard for safety. With a legal limit for alcohol use when driving as a standard, the results show that after 17–19 hours of wakefulness, subjects' performance on many tests had dropped to that found at the legal limits for safe driving. Many people remain awake for periods of 16 hours or more for reasons of work, family, or social life. These results suggest that after this duration of wakefulness fatigue reaches a level that can compromise safe performance.

The results also imply that many countries which set allowable BACs at the point that compromises safe performance should consider developing similar standards for fatigue to ensure that people who have had 18 hours or longer without sleep are kept from at risk behaviours such as driving, piloting aircraft, or operating machinery.

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Vancouver style

All manuscripts submitted to *Occup Environ Med* should conform to the uniform requirements for manuscripts submitted to biomedical journals (known as the Vancouver style.)

Occup Environ Med, together with many other international biomedical journals, has agreed to accept articles prepared in accordance with the Vancouver style. The style (described in full in the *JAMA*[1]) is intended to standardise requirements for authors, and is the same as in this issue.

References should be numbered consecutively in the order in which they are first mentioned in the text by Arabic numerals on the line in square brackets on each occasion the reference is cited (Manson[1] confirmed other reports[2][3][4][5]). In future references to papers submitted to *Occup Environ Med* should include: the names of all authors if there are three or less or, if there are more, the first three followed by *et al*; the title of journal articles or book chapters; the titles of journals abbreviated according to the style of *Index Medicus*; and the first and final page numbers of the article or chapter. Titles not in *Index Medicus* should be given in full.

Examples of common forms of references are:

1 International Committee of Medical Journal Editors. Uniform requirements for manuscripts submitted to biomed journals. *JAMA* 1993;**269**:2282-6.
2 Soter NA, Wasserman SI, Austen KF. Cold urticaria: release into the circulation of histmaine and eosinophil chemotactic factor of anaphylaxis during cold challenge. *N Engl J Med 1976;***294**:687-90.
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Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication

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Exhibit 30:

Drew Dawson, Nicole Lamond, Katharine Donkin, and Kathryn Reid, *Quantitative Similarity Between the Cognitive Psychomotor Performance Decrement Associated with Sustained Wakefulness and Alcohol Intoxication*, Queensland Mining Industry Health and Safety Conference Proceedings (1998)

QUANTITATIVE SIMILARITY BETWEEN THE COGNITIVE PSYCHOMOTOR PERFORMANCE DECREMENT ASSOCIATED WITH SUSTAINED WAKEFULNESS AND ALCOHOL INTOXICATION

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INTRODUCTION

Since the industrial revolution shiftwork has become an increasingly common work practice. It has been estimated that 15-20% of the working population in industrialised countries are currently employed on some form of non-standard work schedule (Knauth, 1993; Baker, 1980). While the economic benefits of shiftwork are self evident (Harrington, 1978), the benefits are accompanied by significant health and social costs (Mitler at al, 1988; Moore-Ede et al, 1985; Spelton et al, 1993). Research studies over the last 20 years have clearly identified shiftwork as an occupational health and safety risk factor (Akerstedt, 1995a).

Reduced opportunity for sleep and reduced sleep quality are generally considered to be the major risk factors associated with shiftwork related accidents (Mitler et al, 1988; Leger, 1994; Akerstedt et al, 1994). Not surprisingly, the combination of these factors leads to increased fatigue, lowered levels of alertness and impaired performance on a variety of cognitive psychomotor performance tasks (Harrington, 1978).

Experimental studies have shown that sustained wakefulness (SW) impairs several components of performance including hand-eye coordination, decision-making, memory, cognition, visual search performance and speed and accuracy of responding (Linde et al, 1992; Fiorica et al, 1968; Babkoff et al, 1988). In addition to cognitive factors, affective components of behaviour such as motivation, and mood are altered as the duration of SW increases (Babkoff et al, 1988; Bohl, 1993).

From the studies cited above it is clear that there is a general consensus that cognitive psychomotor performance is impaired by the sleep disruption and extended wakefulness associated with shiftwork (Akerstedt et al, 1994). Moreover, this performance impairment is associated with an increased risk of accident (Dinges, 1995).

Surprisingly, however, policy makers in western industrialised countries have generally not legislated to manage and control fatigue in a manner commensurate with the statistical risks associated with it. This attitude is in stark contrast to the response to alcohol-related performance impairment. Policy makers and the community have frequently proscribed work and/or the operation of dangerous equipment under the influence of alcohol. Given that the effects of SW are qualitatively similar to the effects of even moderate alcohol intoxication (Klein et al, 1970), it is paradoxical that fatigue-related performance impairment has not been subject to similar levels of regulatory intervention. This failure to address the occupational, health and safety impact of fatigue may, in part, reflect a failure to provide policy makers with a readily understood index of the relative risk associated with sleep loss and fatigue.

The current studies sought to express the impairment associated with fatigue equivalent to those currently accepted by policy makers and the community. That is, by expressing the performance impairment as its equivalent level of alcohol intoxication. By expressing the performance impairment associated with fatigue in terms of its equivalent BAC it is hoped to provide an easily-grasped index of comparative impairment.

METHODS

Study One

Subjects

Forty subjects (27 male; 13 female) gave informed consent to participate in the study. Subject ranged from 18 years to 32 years of age (mean 21.1 (3.7) years). The subjects selected were recruited using advertisements placed around the University of Adelaide. Volunteers were required to complete a general health questionnaire prior to the study. Subjects who had a current health problem, a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol or affect sleep patterns were also excluded. Subjects who did not drink alcohol, or who habitually consumed more than 6 standard drinks per day were excluded.

Procedure

All investigations were conducted at the Centre for Sleep Research at the Queen Elizabeth Hospital. Subjects participated in a randomised cross-over design involving two experimental conditions,

1. A sustained wakefulness condition (SW).
2. An alcohol condition (A).

The two conditions were administered at least one week apart to allow subjects time to recover.

See Figure 1 for a schematic representation of the experimental protocol.

A previous pilot study for this protocol (Dawson et al, 1995) indicated that there was no performance decrement associated with the placebo condition, and that all subjects could correctly identify whether they were intoxicated or not. Since all subjects were regular social drinkers (4-8 drinks/week), and therefore experienced in the effects of alcohol a placebo condition was not included in this protocol.

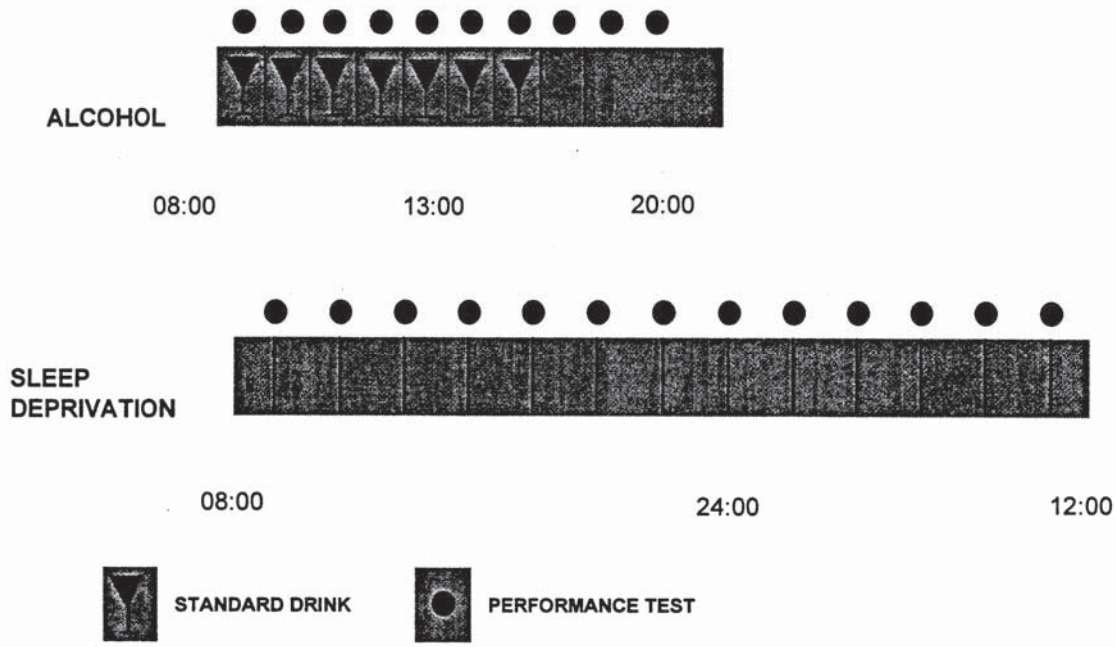

Figure 1. Schematic representation of the protocol for the sustained wakefulness (SW) and alcohol (A) experimental conditions. The alcohol condition commenced at 0800 hours. Subjects consumed 10mg of ethanol in orange juice every half hour until 1600h or until they reached a BAC of 0.10%. Every 30 minutes, subjects were breathalysed, completed three performance tests and then, if necessary, consumed another alcoholic beverage. The sleep deprivation condition commenced at 0800. Subjects completed three performance tests every 30 minutes until 1200h the following day.

Training Session

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of each study period. They were required to complete 40 OSPAT tests to familiarise themselves with the assessment procedure and to minimise improvement in performance resulting from learning.

Sustained Wakefulness Condition

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of the study period and completed a training session before going to sleep at approximately 11:00 p.m. Subjects were woken at 7a.m. the following morning, after breakfast at approximately 7:45 a.m., 9 practice OSPAT tests were completed. Subjects then completed three performance tests at half hourly intervals from 8:00 a.m. until 12:00 p.m. the following day. In between tests, subjects were allowed to read, watch television and play games. Careful monitoring by research staff ensured wakefulness over the entire 28 hour period.

Alcohol Condition

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of the study period and were required to complete a training session before going to sleep at approximately 11:00 p.m. Subjects were woken at 7 a.m. the following morning, after breakfast at approximately 7:45 a.m, 9 performance tests were completed. From 8:00 a.m. subjects underwent a breath test, completed three OSPAT tests and consumed an alcoholic drink at half hourly intervals. If a BAC of 0.1% was reached no further alcohol was given. Subjects were not informed of the BAC at anytime during the test period. All drink consumption and performance testing ceased at 4:00 p.m., but subjects were required to stay in the sleep laboratory under supervision until their BAC returned to 0%.

Subjects ate standard hospital meals during the study, although food and drinks containing caffeine were prohibited. Subjects were required to sit quietly and watch television or play boardgames during their time in the laboratory. Subjects were not permitted to exercise, shower or bath.

Equipment

Cognitive psychomotor performance

Cognitive psychomotor performance was measured using the Occupational Safety Performance Assessment Test (OSPAT). OSPAT is a unpredictable tracking task that subjects perform on a computer workstation. In simple terms, the task required subjects to keep a randomly moving cursor in the centre of three concentric circles, using a standard trackball. After the cursor is 'centred' the cursor moves to a random position away from the centre and the subject is required to 're-centre' the cursor. Subjects were seated in front of the workstation in an isolated room, free of distraction and were instructed to manipulate the track-ball using their dominant hand. Subjects completed three one-minute tests in each testing session and received no feedback between tests in order to avoid the knowledge of results affecting performance levels.

A global performance measure for each test is determined by summing the 'error' distance between the cursor and target and the rate at which the subject adapted to the random changes. This measure indicates how "well" the subject performed the task.

Blood alcohol

During the alcohol condition subjects were given alcohol loaded drinks consisting of 95% ethanol and orange juice at a rate designed to increase their BAC to 0.10% over a 4-6h period. Prior to all breath tests subjects were required to rinse their mouths with water. A standard calibrated breathalyser was used to estimate blood alcohol concentration (BAC) (Lion Alcolmeter S-D2, Wales). The breathalyser was accurate to 0.005% BAC.

Study Two

Subjects

Eight subjects (5 male; 3 female) gave informed consent to participate in the study. Subjects ranged from 19 years to 25 years of age (mean 20.25 (± 1.28) years). Method of recruitment and exclusion criteria were the same as those employed in study one.

Procedure

Subjects participated in a two-condition protocol similar to that in study one. In addition to the two experimental conditions, subjects attended a separate training day.

Training Session

During the week prior to commencement of the experimental conditions, subjects were required to attend the lab for a training session to familiarise themselves with the tasks used to assess performance and to minimise improvement in performance resulting from learning. They were required to complete each test until their performance reached a plateau.

Sustained Wakefulness Condition

Subjects arrived at the sleep laboratory at 8:00 p.m. on the night prior to commencement of the study. Prior to retiring at approximately 11:00 p.m., subjects completed a re-training session to reacquaint themselves with the performance tasks. During this session, they completed practice tests for each of the performance tasks in the study. Subjects were woken at 7:00 a.m. the following morning and a baseline testing session was completed at 8:00 a.m. Subjects then completed a testing session every hour, until 11:00 p.m. the following day.

Alcohol Condition

Subjects arrived at the sleep laboratory at 8:00 p.m. on the night prior to commencement of the experimental period. Before retiring for the night, at approximately 11:00 p.m., subjects completed a practice session as outlined above. Subjects were woken at 7:00 a.m. the following morning and completed a baseline testing session at 8:00 a.m. From 9:00 a.m. subjects completed a testing session every hour. As in study one, subjects underwent a breath test and consumed an alcoholic beverage at half hourly intervals.

Equipment

<u>*Cognitive psychomotor performance*</u>

Cognitive psychomotor performance was measured using a standardised computer based test battery (Worksafe Integrated Test Battery). The apparatus for the battery consists of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. The test battery is based on a standard information processing model (Wickens, 1984). According to this model there are seven key information processing functions (see Figure 2).

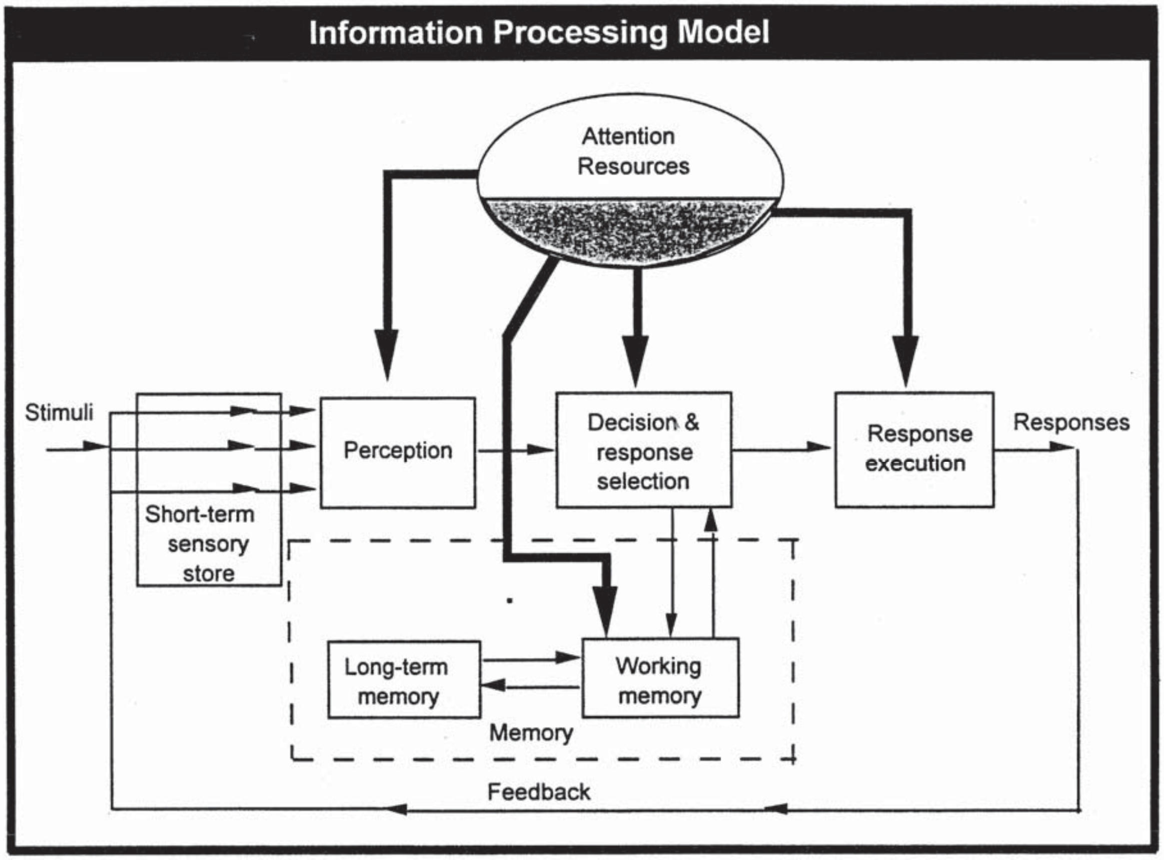

Figure 2. Synthesised information processing model indicating seven key information processing functions. Adapted from Wickens (1984).

The test battery software permits any combination of 12 visual and/or auditory tasks. The four tasks used in this study were (in order of complexity),

1. Simple Reaction Time (SRT)
2. Predictable Tracking (PT)
3. Vigilance (VIG)
4. Grammatical Reasoning (GR)

Each of these tasks was used to measure specific components of cognitive psychomotor performance according to the combinations outlined in Table 1.

	Simple Reaction Time	Predictable Tracking	Vigilance	Grammatical Reasoning
Short-term sensory store				
Perception	P	P	P	
Decision & Response selection			P	P
Working memory				P
Long-term memory				P
Attention resources		P	P	P

Response execution	P	P	P	

Table 1. Components of cognitive functioning required for performance of each test.
P: Primary information processing component skill(s) assessed by the task.

Performance Tasks

Simple Reaction Time

Simple reaction time is an unpredictable task that measures both reaction time and response time. Subjects were instructed to depress the home button on a tri-button unit. Then, using the same finger, they were required to depress the left hand response button when a stimulus was observed, returning to, and depressing, the home button afterwards.

Predictable Tracking

In the predictable tracking task , subjects were required, with the use of a joystick, to keep a cursor on, or as close as possible to, a target box. In this task, the whole track the target box is going to make was revealed to the subject in the set-up lap.

Vigilance

Vigilance is an unpredictable task that measures both accuracy and response time. To begin this task, subjects were instructed to have their hand hovering over the display area, ready to press any of the six black buttons or the single red button. Subjects were instructed to press the black button corresponding to the illuminated light, if only one light was illuminated, and to press the red button if two lights were illuminated simultaneously.

Grammatical Reasoning

Grammatical reasoning, the most complex of the tasks, measures accuracy, response time and reaction time. Using the same tri-box as SRT, the task began after the subject depressed the home button. Subjects were instructed to keep their finger on the home button, until a decision as to the truth/falsity of a specific statement (displayed on the monitor) had been made, and then to press the left (true) or right (false) button accordingly, using the same finger. After responding, subjects were required to return to and depress the home button, to initiate the next statement. Subjects were instructed to concentrate on accuracy rather than speed.

ANALYSIS OF RESULTS

Cognitive psychomotor performance data was analysed using relative performance. That is, each individual's performance was expressed relative to their personal baseline. In study one, the baseline measure was calculated by averaging the scores of each individuals nine practice trials carried prior to the first 8:00 a.m. performance test on the first of the two counterbalanced experimental conditions. In the second study the scores of each individuals 8:00 a.m. test session were used as the baseline measure.

Figure 3 indicates that subjects in the first study rapidly mastered the performance test during the practice session. There was little variation in mean relative performance after completing 5 tests and by 25 tests subjects had reached a clear performance plateau. Similar findings were observed in the second study.

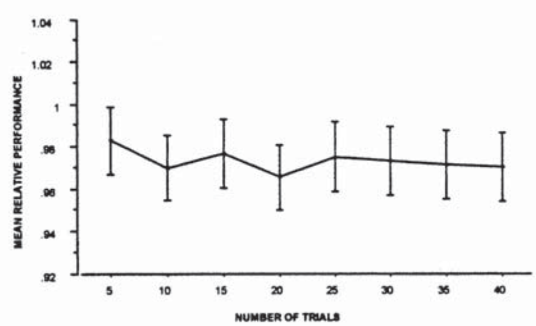

Figure 3. Mean relative performance for training session trials in the night prior to the first experimental condition (Study one). Error bars indicate s.e.m.

Alcohol Intoxication

To determine the relative effect of alcohol on performance, mean relative performance scores for all subjects were collapsed into 0.005% BAC intervals to determine the average performance decrement per unit increase of BAC. The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.005% interval. Figure 4, shows the regression line between estimated BAC and mean relative performance in the alcohol condition.

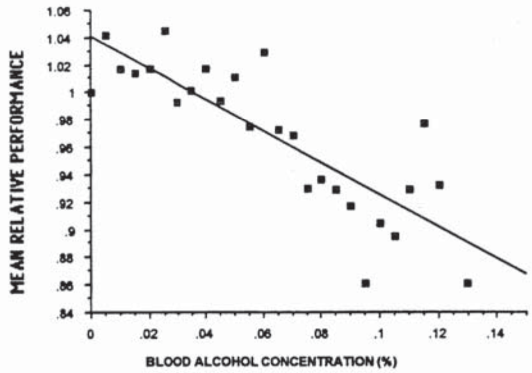

Figure 4. Scatter plot and linear regression of mean relative performance levels against blood alcohol concentrations between 0.00-0.13%.

The regression analysis indicated a significant linear correlation between subject's mean BAC and mean relative performance (Table 2). It was found that for each 0.01% increase in BAC, performance decreased by 1.16%. Thus, at a mean BAC of 0.10% mean performance decreased, on average, by 11.6%.

PERFORMANCE TEST	DF	F	P	R2
Study One Ospat	1,24	54.4	<0.05	0.69
Study Two Simple Reaction Time	1,7	13.41	<0.05	0.66
Predictable Tracking	1,7	9.61	<0.05	0.58
Vigilance				
Response Time	1,8	5.14	N.S.	0.39
Response Variability	1,6	1.63	N.S.	0.17
Grammatical Reasoning				
Response Time	1,6	7.33	<0.05	0.45
Accuracy	1,6	7,27	<0.05	0.39

Table 2. Regression analyses between mean relative performance and mean BAC.

Sustained Wakefulness

Performance in the SW condition was analysed by averaging performance data into two-hourly bins across the 28 hours of the study. Since there is a strong non-linear (circadian) component to the performance data and shiftworkers do not typically spend less than 10 or more than 26 hours awake (Australian Bureau of Statistics, 1993), the linear performance decrement per hour of wakefulness, was calculated using a linear regression between the tenth and twenty-sixth hour of wakefulness. This was methodologically appropriate since analysis of the performance data across this period shows a significant linear component (p<.05) and a non-significant non-linear component. Figure 5. illustrates this relationship plotting mean relative performance (from study one) against hours of wakefulness between the tenth and twenty-sixth hours.

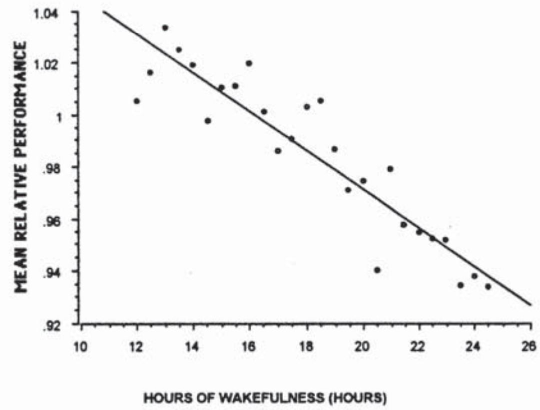

Figure 5. Scatterplot and linear regression of mean relative performance levels against prior wakefulness between the 10th and 26th hour of sustained wakefulness.

Regression analysis revealed a significant linear correlation between mean relative performance and hours of wakefulness (Table 3). Between the tenth and twenty-sixth hours of wakefulness, performance relative to baseline decreased by 0.74%/h.

PERFORMANCE TEST	DF	F	P	R2
Study One Ospat	1,24	132.9	<0.05	0.92
Study Two Simple Reaction Time	1,6	14.1	<0.05	0.70
Predictable Tracking	1,6	6.0	<0.05	0.5
Vigilance				
Response Time	1,6	22.53	<0.05	0.79
Response Variability	1,6	16.91	<0.05	0.74
Grammatical Reasoning				
Response Time	1,6	44.24	<0.05	0.88
Accuracy	1,6	14.42	<0.05	0.71

Table 3. Regression analyses between mean relative performance and hours of wakefulness.

The results discussed above illustrate the effects of SW and alcohol intoxication on cognitive psychomotor performance. However, the aim of the present study was to express the effects of fatigue as a blood alcohol equivalent. Figures 6 to 9 illustrate the comparative effects of SW and alcohol consumption on performance by plotting mean relative performance and BAC against hours of wakefulness.

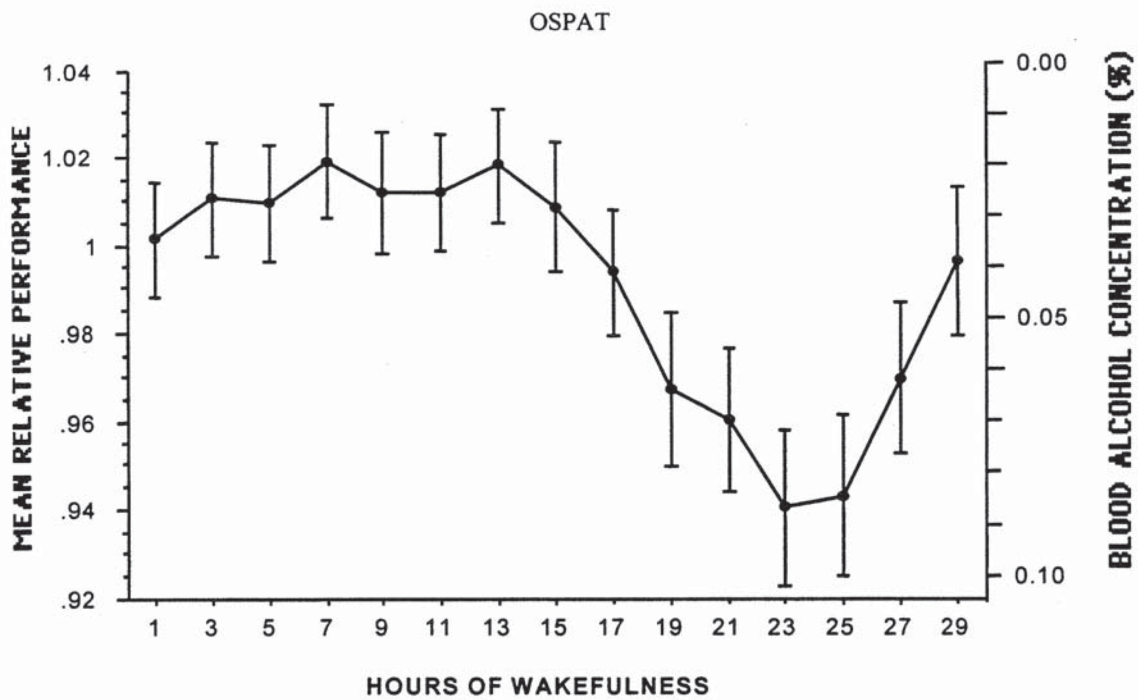

Figure 6. Performance (OSPAT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate one s.e.m.

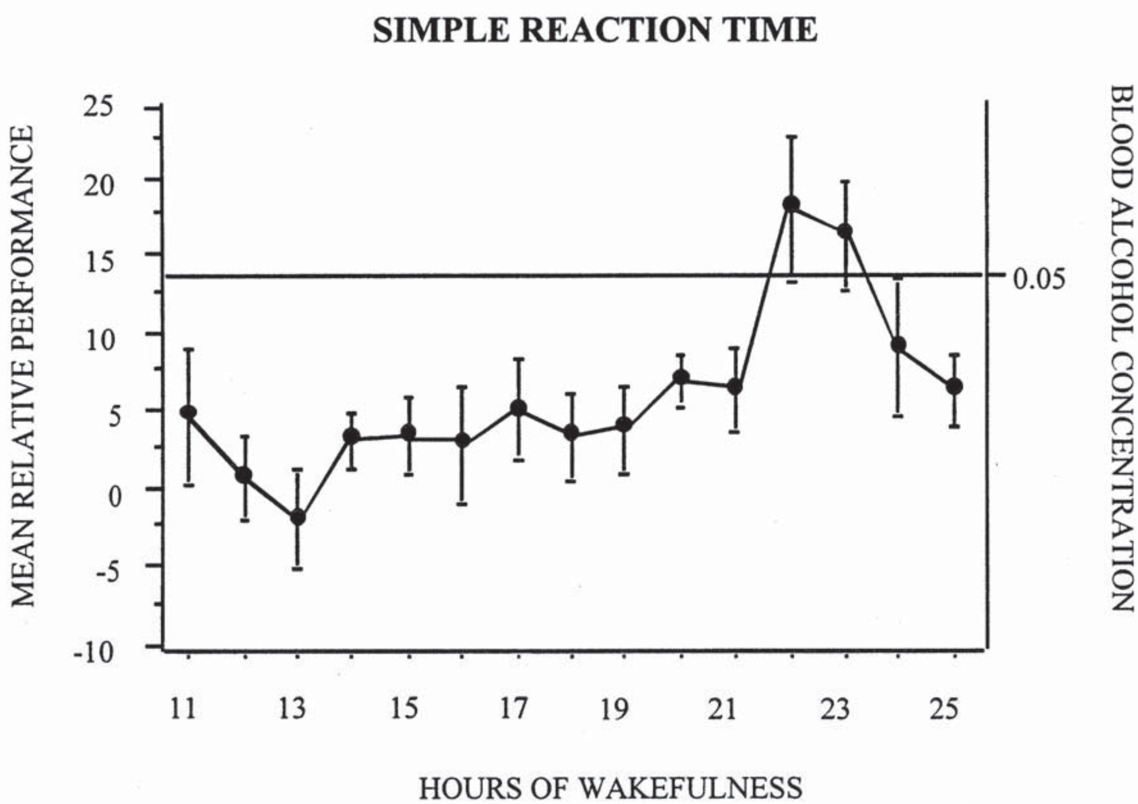

Figure 7. Performance (SRT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate one s.e.m.

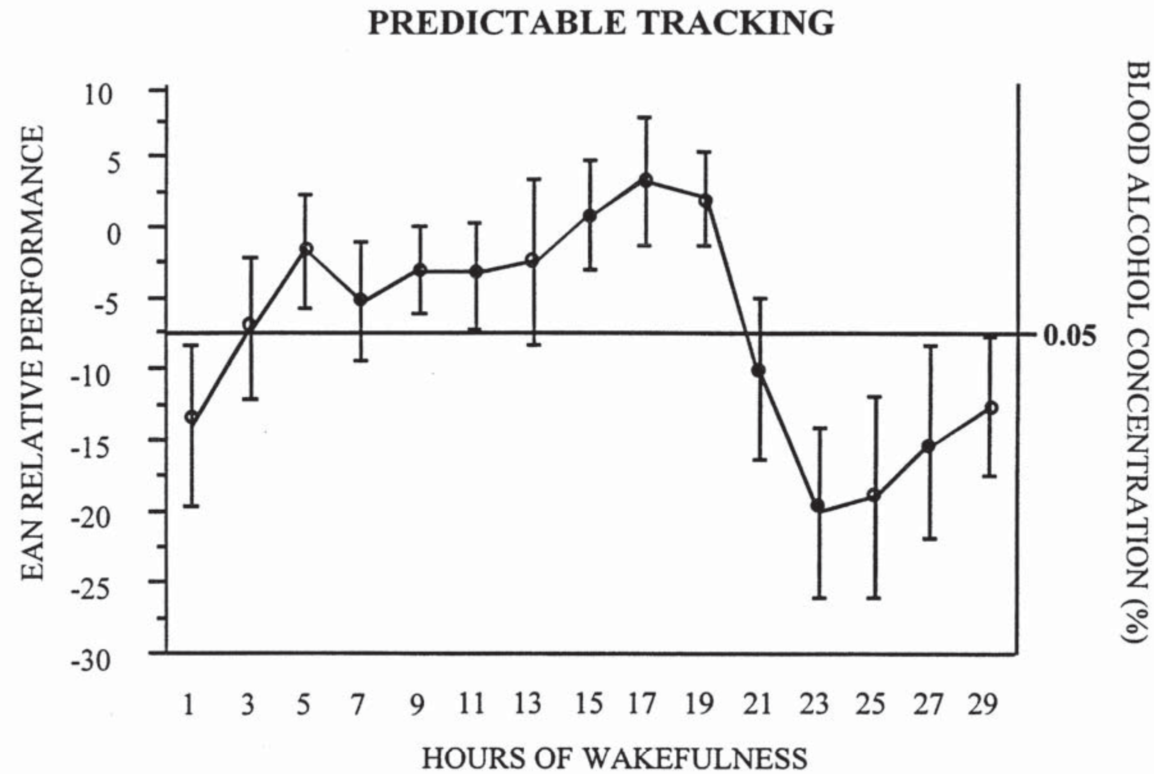

Figure 8. Performance (PT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate one s.e.m.

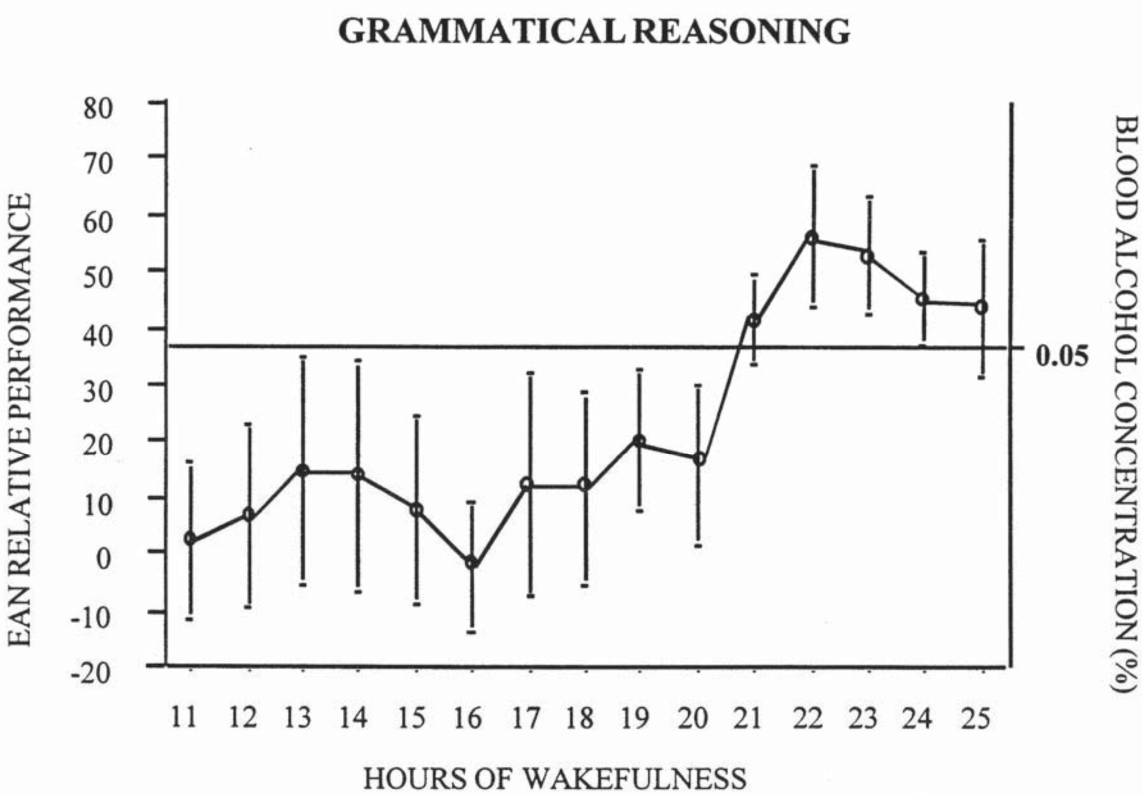

Figure 9. Performance (GR accuracy) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate one s.e.m.

By equating the two rates at which performance declines, (i.e. % decline / hour of wakefulness and % decline / BAC) it was calculated that the performance decrement for each hour of wakefulness was equivalent to the performance decrement observed with a 0.04% rise in BAC (study one data). Therefore, after 24 hours of SW cognitive psychomotor performance in study one decreased to a level equivalent to the performance observed at a BAC of 0.096%. While in the second study, after 24, 21, 21 and 13 hours of SW, performance on tasks of simple reaction time, predictable tracking and grammatical reasoning (accuracy and response time), respectively, decreased to a level equivalent to the performance observed at a BAC of 0.05%.

DISCUSSION

Cognitive psychomotor performance levels for all tests except for vigilance decreased significantly in the alcohol condition. Similarly, cognitive psychomotor performance levels decreased significantly for all performance tests in the SW conditions. Comparison of the two effects indicated that moderate levels of sustained wakefulness produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

In the alcohol condition increasing blood alcohol concentrations were associated with a significant linear decline in cognitive psychomotor performance. For example, in study one mean relative performance in the alcohol condition was impaired by approximately 5.8% at a BAC of 0.05% and by 11.6% at a BAC of 0.10. Overall, mean relative performance declined by approximately 1.16% per 0.01% BAC. These results are consistent with previous findings that suggest that cognitive psychomotor performance declines linearly with increasing intoxication between 0.0-0.075% BAC (Billings et al, 1991).

It is important to note that there was no decrease in mean relative performance up until a BAC of 0.03%. This is similar to the findings of Wilkinson and Colquhoun (1968) who also reported an increase in performance on a choice serial reaction test up until a BAC of 0.032%. This result is thought to reflect the fact that alcohol acts as a stimulant at low blood alcohol concentrations.

In contrast, cognitive psychomotor performance in the SW condition showed a more complex relationship. Mean relative performance showed three distinct phases. In the first phase (0-10 hours) performance remained relatively stable at a plateau. In the second phase (10-26 hours) performance declined linearly. During the third interval (26-28 hours) mean relative performance increased again presumably reflecting the well reported circadian variation in cognitive psychomotor performance (Folkard et al, 1993).

Since few shiftworkers remain awake for less than 10 or more than 26 hours between shifts (Australian Bureau of Statistics, 1993), the comparative analysis focussed on the second phase. Between the 10th and 26th hours mean relative performance, showed a strong linear decline of approximately 0.74 % per hour. The performance decline observed between hours 10 and 26 is consistent with previous studies, documenting cognitive psychomotor performance decreases for periods of sustained wakefulness between 12 and 86 hours (Linde et al, 1992; Storer et al, 1989; Fiorica et al, 1968).

While the results in each of the individual experimental conditions have, in and of themselves been previously established (Linde et al, 1992; Storer et al, 1989; Wang et al, 1992; Gustafon, 1986; Roache et al, 1992) equating the effects is relatively novel.

The results of this comparison indicate that the effects of 10-26 hours of SW from 1800-1000 hours, and moderate alcohol consumption have quantitatively similar effects on cognitive psychomotor performance. Although there are previous anecdotal reports indicating qualitative similarities between fatigue and alcohol intoxication (Klein et al, 1970; Kleitman, 1939), these studies establish the quantitative similarities of the two forms of impairment. In study one, equating the performance impairment between the 10th and 26th hour indicated a mean BAC equivalent of approximately 0.05% after 18 hours and 0.096% after 24 hours. If the results of this study were generalised to an applied setting they suggest that between 0300h and 0800h on the first night shift a shiftworker would show a cognitive psychomotor performance decrement similar to or greater than the legally proscribed BAC for many industrialised countries.

The second study further expanded on these findings. The results of the comparisons indicate that sleep deprivation effects specific components of performance differently, dependent on their relative degree of complexity. That is to say, sustained wakefulness effects more complex cognitive psychomotor abilities before simpler abilities. In accordance with the Information Processing Model earlier referred to, the simplest measure of performance incorporated in this study, simple reaction time, required only perception and response execution functions. It was found that 24 hours of sleep deprivation were necessary to produce a performance decrement comparable to that associated with a BAC of 0.05%. Whereas for performance on the predictable tracking task, a slightly more complex task that also requires attention resource functions, a decrement equivalent to that of BAC of 0.05% was observed after 21 hours of sustained wakefulness.

Similarly, 21 hours of sleep deprivation produced a decrement in performance on the grammatical reasoning task equivalent to that associated with a BAC of 0.05%. It is interesting to note, however, that a decrement in the speed component of grammatical reasoning, equivalent to that associated with a BAC of 0.05%, was observed after only 13 hours of sustained wakefulness (graph not shown). While this may at first contradict the suggestion that more complex abilities are affected sooner by sustained deprivation, it must be remembered that subjects were told to concentrate on accuracy in this task, rather than speed. Indeed, the apparent speed-accuracy trade-off observed in the grammatical reasoning task is similar to that found in previous studies (Craig and Condon, 1985).

The data from both studies supports the idea that sustained wakefulness may carry a risk comparable with moderate alcohol intoxication since approximately 50% of shiftworkers on 8 hour shift patterns typically spend at least 24 hours awake on the first night shift in a roster (Knauth et al, 1981). Furthermore, the highest level of impairment observed in this study (~0.096% BAC) would occur at the end of a typical night shift (i.e. 0600-0900h) and would frequently coincide with the trip home for many shiftworkers.

While the results of this study clearly illustrate the comparative risks associated with sustained wakefulness for the first night shift, these results may underestimate the effect of night work in many real world settings. Previous research suggests that the performance impairment associated with shiftwork may be even greater on subsequent night shifts because of the reduced recuperative value of poor daytime sleep (Akerstedt, 1995b). Several studies have reported that the performance decrements, reduced alertness and fatigue reported by night shift workers is greater on the second and third night shift (Tilley et al, 1981). If this is the case, then it may be reasonable to assume that the alcohol impairment equivalent on these nights may be even greater than reported here for the first night.

However, it is not a simple process of calculating the performance decrement for hours of wakefulness, since shiftworkers may be sleeping at different times of the day and night. In addition they may have accumulated sleep loss from night one to three of their work schedule. Therefore, it may be useful to use longer experimental protocols to model actual shift schedules and establish the BAC equivalence for the performance decrement associated with the fatigue that can accumulate over a sequence of night shifts.

Taken together, the results from this study support the idea that the performance impairment and, by inference, the risk associated with sustained wakefulness across the night are not insubstantial and are quantitatively similar to those observed for moderate alcohol intoxication in social drinkers.

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Exhibit 31:

Drew Dawson and Kathryn Reid, *Fatigue, Alcohol, and Performance Impairment*, 388 Nature 235 (1997)

Fatigue, alcohol and performance impairment

Reduced opportunity for sleep and reduced sleep quality are frequently related to accidents involving shift-workers[1–3]. Poor-quality sleep and inadequate recovery leads to increased fatigue, decreased alertness and impaired performance in a variety of cognitive psychomotor tests[4]. However, the risks associated with fatigue are not well quantified. Here we equate the performance impairment caused by fatigue with that due to alcohol intoxication, and show that moderate levels of fatigue produce higher levels of impairment than the proscribed level of alcohol intoxication.

Forty subjects participated in two counterbalanced experiments. In one they were kept awake for 28 hours (from 8:00 until 12:00 the following day), and in the other they were asked to consume 10–15 g alcohol at 30-min intervals from 8:00 until their mean blood alcohol concentration reached 0.10%. We measured cognitive psychomotor performance at half-hourly intervals using a computer-administered test of hand–eye coordination (an unpredictable tracking task). Results are expressed as a percentage of performance at the start of the session.

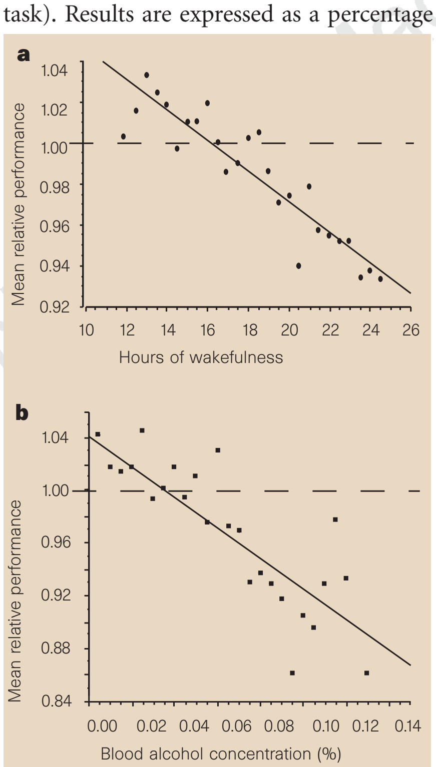

Figure 1 Scatter plot and linear regression of mean relative performance levels against: **a,** time, between the tenth and twenty-sixth hour of sustained wakefulness ($F_{1,24}$=132.9, $P<0.05$, R^2=0.92); and **b,** blood alcohol concentrations up to 0.13%, ($F_{1,24}$=54.4, $P<0.05$, R^2=0.69).

Performance decreased significantly in both conditions. Between the tenth and twenty-sixth hours of wakefulness, mean relative performance on the tracking task decreased by 0.74% per hour. Regression analysis in the sustained wakefulness condition revealed a linear correlation between mean relative performance and hours of wakefulness that accounted for roughly 90% of the variance (Fig. 1a).

Regression analysis in the alcohol condition indicated a significant linear correlation between subject's mean blood alcohol concentration and mean relative performance that accounted for roughly 70% of the variance (Fig. 1b). For each 0.01% increase in blood alcohol, performance decreased by 1.16%. Thus, at a mean blood alcohol concentration of 0.10%, mean relative performance on the tracking task decreased, on average, by 11.6%.

Equating the two rates at which performance declined (percentage decline per hour of wakefulness and percentage decline with change in blood alcohol concentration), we calculated that the performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004% rise in blood alcohol concentration. Therefore, after 17 hours of sustained wakefulness (3:00) cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. This is the proscribed level of alcohol intoxication in many western industrialized countries. After 24 hours of sustained wakefulness (8:00) cognitive psychomotor performance decreased to a level equivalent to the performance deficit observed at a blood alcohol concentration of roughly 0.10%.

Plotting mean relative performance and blood alcohol concentration 'equivalent' against hours of wakefulness (Fig. 2), it is clear that the effects of moderate sleep loss on performance are similar to moderate alcohol intoxication. As about 50% of shift-workers do not sleep on the day before the first night-shift[5], and levels of fatigue on subsequent night-shifts can be even higher[6], our data indicate that the performance impairment associated with shift-work could be even greater than reported here.

Our results underscore the fact that relatively moderate levels of fatigue impair performance to an extent equivalent to or greater than is currently acceptable for alcohol intoxication. By expressing fatigue-related impairment as a 'blood-alcohol equivalent', we can provide policy-makers and the community with an easily grasped index of the relative impairment associated with fatigue.

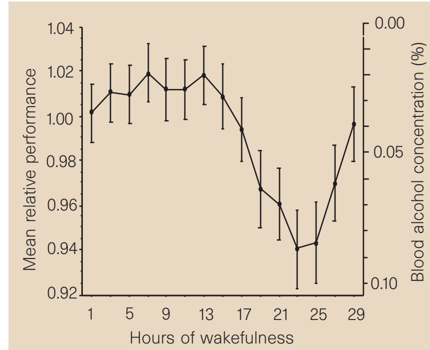

Figure 2 Performance in the sustained wakefulness condition expressed as mean relative performance and the percentage blood alcohol concentration equivalent. Error bars ± s.e.m.

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Entropy difference between crystal phases

In a recent Letter[1], Woodcock reported the results of a molecular dynamics study in which he claims to have finally determined the free-energy difference between the hexagonal close-packed (h.c.p.) and face-centred cubic (f.c.c.) phases of a crystal of (classical) hard spheres. Woodcock reports a small positive difference in the reduced Gibbs free-energy, which is equivalent to a difference in the reduced Helmholtz free-energy of $\Delta F^* \equiv (F_{hcp} - F_{fcc})/RT = 0.005(1)$ at the melting density (R is the gas constant, T is the absolute temperature, and the number in parentheses is the estimated error in the last digit). As Woodcock correctly points out, the calculation of the relative stability of the f.c.c. and h.c.p. phases of hard spheres is a long-standing problem in statistical physics. Attempts to resolve it date back to the work of Alder, Hoover and colleagues[2–5], and most recently, a direct simulation by Frenkel and Ladd[6], obtaining the bounds of Helmholtz free-energy of $-0.001 \leqslant \Delta F^* \leqslant 0.002$. Woodcock's estimate is incompatible with this latter result.

To resolve this issue, we made accurate calculations of the free-energy difference between h.c.p. and f.c.c. hard-sphere crystals both at the melting density (73.6% of the density of regular close packing) and at close packing, using two different methods. We find that $\Delta F^* = 0.0009(2)$ at melting, a result that is quite consistent with the earlier work, but is five times smaller than Woodcock's estimate. Woodcock does not explain how he arrives at an error estimate of 20% — our work suggests that the numerical error in his result must have been four times larger than the entire h.c.p. − f.c.c. free-energy difference.

Nevertheless, we do agree with the sign of Woodcock's estimate — the f.c.c. crystal is indeed more stable than the h.c.p. crystal. This might explain the tendency towards f.c.c. packing seen in some experimental studies of hard-sphere colloids[7]. In one set of simulations, we used the 'Einstein-crystal' method[6,8], simulating crystals of 12,096 hard spheres (slightly larger than the largest system studied by Woodcock), and computed the Helmholtz free-energies of the two phases using a 20-point Gauss–Legendre quadrature. Every point in this quadrature involved a Monte Carlo simulation of 10^5 trial moves per particle, excluding equilibration. We find that the free-energy difference between h.c.p. and f.c.c. at melting is $\Delta F^* = 0.00087(20)$, and at close packing $\Delta F^* = 0.00094(30)$. The statistical error was computed on the basis of the variance in the block averages of the individual Monte Carlo runs[9].

We also performed simulations using a new 'multi-hamiltonian' method (S.-C. M. and D. A. H., manuscript in preparation) that directly equilibrates the h.c.p. and f.c.c. hard-sphere crystals with each other by a set of intermediate states with different interactions but essentially the same free-energy. These latter simulations were done on much smaller samples (64 to 512 spheres) and obtained essentially the same free-energy differences (for 512 spheres, $\Delta F^* = 0.00085(10)$ near melting, and 0.0011(2) at close packing) as the 'Einstein-crystal' simulations, with comparable statistical errors. Statistically significant finite-size effects were detected only for the smallest size (64 spheres) near melting, where ΔF^* dropped to near zero.

In any event, our result for the f.c.c.–h.c.p. free-energy difference for large hard-sphere crystals at melting is much closer to $\Delta F^* = 0$, proposed almost 30 years ago by Alder and co-workers, than to the recent estimate by Woodcock.

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Woodcock replies — I reported the discovery a substantial area of pressure difference (ΔP) between the f.c.c. and h.c.p. single-occupancy-cell models, which arises from a difference in order–disorder transition pressures. The result was a free-energy difference in favour of f.c.c., corresponding to an entropy difference $0.005Nk_B$, over the range $V = 1.00N\sigma^3$ to $1.25N\sigma^3$, with a generous uncertainty (± 0.001), estimated by integrating the standard deviations of sub-averages of ΔP for individual data points. Extension of the computations on either side of the phase transition have since revealed a tail in the pressure difference for $V > 1.25N\sigma^3$ in favour of h.c.p. There is also a weak pressure difference for volumes below melting. I have now obtained more accurate data for these tails, including new data points on both sides of the single-occupancy-cell phase transition (Fig. 1).

I did not originally calculate the pressure difference in the stable crystal range, relying on earlier findings that ΔP up to melting was not detectable by molecular dynamics computation[2], and that these showed the two crystals to have indistinguishable crystal constants C_0 and C_1 (ref. 4). Consequently I assumed no difference between the Gibbs and Helmholtz free-energies in the stable crystal range.

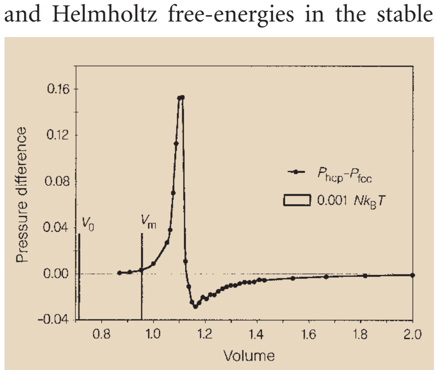

Figure 1 Latest molecular dynamic data for the pressure difference as a function of volume at constant temperature, $\Delta P(V)_T$, between the h.c.p. and f.c.c. single-occupancy-cell crystal structures for hard spheres; V_0 is the close-packed crystal volume and V_m is the volume at melting. The area under this curve is the Helmholtz free-energy difference between the two crystal structures at close packing in units of Nk_BT.

A detectable pressure difference between f.c.c. and h.c.p. crystals below melting, however, has now been computed, both by R. Speedy (personal communication) and myself. This small pressure difference means that the entropy difference at constant volume — which equals the Helmholtz free-energy difference for hard spheres — is not the same as the Gibbs free-energy difference, which determines the stable crystal structure at freezing. However, the correction is small, $\sim 0.000015Nk_BT$.

At the melting volume (V_m) of $0.96N\sigma^3$, I calculate the pressure difference to be $0.0030(5)k_BT/\sigma^3$ ($N = 12{,}000$). Alder *et al.*[3] adopted too large a value for ΔP_m ($0.02k_BT/\sigma^3$), and further guessed wrongly that the absolute difference decreased linearly with density to zero at V_0. In fact they estimated the Helmholtz free-energy difference (ΔF_m–ΔF_0) to be $0.002Nk_BT$ in favour of f.c.c. My data (Fig. 1) show that the pressure difference found at melting actually decreases to negligible values more rapidly, and that the change in free-energy difference between close packing and melting is of the order $0.0003Nk_BT$. The closeness of the result of Alder *et al.* to any of the present results, or indeed to zero, is therefore an irrelevance.

The Einstein-crystal method[10] (used both by Frenkel and Ladd[6] and here by Bolhuis and Frenkel), the multi-hamiltonian method and the Hoover–Ree single-occupancy-cell method, if accurately implemented, should all give the correct answer. I am still working on this problem, but the latest result for the Helmholtz free-energy difference between the h.c.p. and f.c.c. structures (f.c.c. having the lower free-energy) at close packing gives:

$$\Delta F_0 = \int_{V_0}^{\infty} (P_{hcp} - P_{fcc})\,\mathrm{d}V = 0.0026 \pm 0.001 Nk_BT.$$

The change in Helmholtz free-energy difference between close-packing and the melting volume amounts to only $0.0003(1)Nk_BT$, as shown by the tiny, positive area in $\Delta P(V)_T$ up to the melting volume (V_m) (see Fig. 1). Hence, the Helmholtz free-energy difference at the melting volume is $\Delta F_m = 0.0023(10)Nk_BT$. There remains a quantitative disagreement between my result and the other two methods, but my original conclusion that the f.c.c. phase is everywhere the more stable crystal phase for hard spheres is confirmed by all the new results. It is also gratifying that the result for the tiny free-energy difference between close packing and melting show a remarkable consistency, within the error bars, by all three methods.

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Metallothionein in snail Cd and Cu metabolism

Terrestrial snails tolerate elevated concentrations of cadmium and copper, accumulating both metals in their soft tissues[1]. The snails are able to inactivate the toxic cadmium while meeting their metabolic requirement for copper. Here we report evidence for the metabolic discrimination between the two metals based on the existence of distinct metallothionein isoforms, one dedicated to cadmium detoxification and another to copper regulation.

Even snails living in relatively unpolluted environments have the exceptional ability to concentrate cadmium — more than many other terrestrial invertebrates — in the midgut gland[2]. In contrast, copper, which is an essential constituent of the oxygen-carrying protein haemocyanin[3,4], is predominantly present in the snail's foot and mantle[1]. The concentration of copper is kept constant, with animals quickly eliminating any excess that may have entered the tissue after environmental exposure[1]. We have recently isolated and characterized two metallothionein isoforms from terrestrial helicid species, differentially involved in the handling of cadmium and copper.

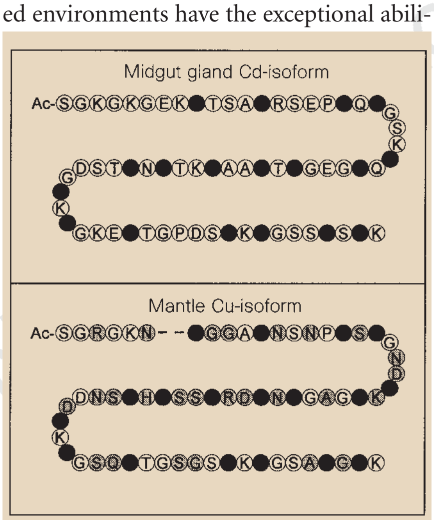

Figure 1 Primary structures of the cadmium- and copper-binding metallothionein isoforms from the midgut gland and mantle of *H. pomatia*. Residues are indicated using single-letter code, with cysteines in black. The N termini are acetylated (Ac). Substituted residues are indicated in grey in the copper-binding isoform. The cadmium-binding isoform was purified and sequenced as described earlier[5]. The copper-binding isoform was purified from mantle tissue by combined gel permeation, ion-exchange chromatography, and reversed-phase HPLC. After endoproteinase digestion (trypsin, Lys-C and Arg-C) of *S*-methylated protein, peptides were sequenced by collision-induced tandem mass spectrometry (API III, Sciex, Canada) using argon as the collision gas (4×10^{14} molecules cm^{-2}).

One of these isoforms is present in the midgut gland of terrestrial snails. We identified it as a class-I metallothionein[5] with a typically low molecular mass (6.62×10^6; 6,620K), containing 66 amino acids, 18 of which are cysteines. Its amino-terminal serine is acetylated (Fig. 1). This isoform occurs in several variants in helicid snails, including *Helix pomatia* and *Arianta arbustorum*[6,7].

The function of this isoform is the detoxification of cadmium, binding 85–95% of all cadmium accumulated in the snail soft tissues. The cadmium-binding metallothionein isoform can be isolated in a pure form from the midgut gland of metal-exposed snails, and has a molar metal ratio of Cd:Cu:Zn of 100:2:6.6 in the native protein and a stoichiometry of six cadmium atoms per protein molecule (determined by spectrophotometric metal titration under nitrogen atmosphere). Its concentration increases linearly with increasing cadmium concentrations in the midgut gland (Fig. 2a).

We have recently isolated another isoform from the mantle of *Helix pomatia*. Apart from its acetylated amino-terminal serine, the primary structure is very different to the cadmium-binding metallothionein. It has a different molecular mass (6,247K), and many amino-acids between the conserved cysteine residues have been substituted (Fig. 1). *In vivo*, this isoform is almost exclusively conjugated with copper, with a molar metal ratio of Cu:Cd:Zn of 100:1:6. We determined the stoichiometry using combined atomic absorption spectrophotometry, amino-acid analysis and electrospray mass spectrometry, as roughly six copper atoms per protein molecule.

The concentration of the mantle isoform and its exclusive preference for copper remain unaffected when snails are exposed to cadmium (Fig. 2b), even if this metal is injected into the mantle tissue. In this case, most of the administered cadmium is quickly eliminated from the mantle and redistributed to the midgut gland, but virtually none of the metal becomes bound to the copper-specific metallothionein isoform. In addition, the concentration of this isoform is barely affected by exposure of animals to large amounts of copper (Fig. 2b). Our results indicate that the metallothionein isoform in the mantle of terrestrial snails is concerned with the regulation of copper, probably in connection with haemocyanin synthesis (as the gastropod mantle is an important site of production of this copper-containing protein)[8].

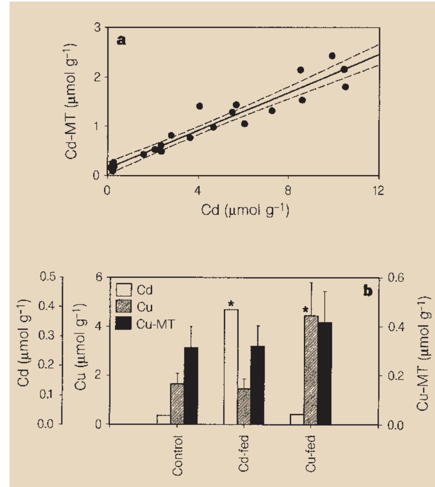

Figure 2 a, Linear relationship (bold line; regression coefficient $r=0.96$), with 95% confidence limits (hatched lines) between molar concentrations (on a tissue dry-mass basis) of Cd and Cd–metallothionein (Cd-MT) in the midgut gland of *H. pomatia* fed on a Cd-enriched diet (3.5–955 μg Cd per g dry mass) for 14 days. **b,** Molar concentrations of Cd, Cu, and Cu–metallothionein (Cu-MT) in the mantle of *H. pomatia* after feeding the animals on uncontaminated salad (control) or on Cd-enriched (Cd-fed; 260 μg per g dry weight) or Cu-enriched diets (Cu-fed; 530 μg per g dry weight) for 14 days. Mean concentration±s.d. ($n=7$). Asterisks indicate significant differences ($P<0.01$) from control values (Student's *t*-test). Concentrations of Cd–metallothionein and Cu–metallothionein were determined by modified Cd- and Cu-saturation assays[11] (removing Cu from the holo-metallothionein with ammonium-tetrathiomolybdate). Similar results (not shown) were obtained after injecting Cd and Cu into mantle tissue.

Until now, the simultaneous handling of different metals by metallothioneins has been explained on the basis of metal-specific preferences of the two metal-binding domains of the molecule[9,10]. The existence of specific metallothionein isoforms dedicated to cadmium detoxification and copper regulation in snails suggests an alternative model to explain the mechanisms of multifunctionality in these proteins.

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Exhibit 32:

2011 U.S. Air Carrier Net Income

2011 U.S. Air Carrier Reported Net Income

Source: BTS Form 41 data (Item 98990, Schedule P-1.2)

Passenger		Net Income
Air Wisconsin Airlines Corp	$	13,765,230
AirTran Airways Corporation	$	(24,745,810)
Alaska Airlines Inc.	$	256,434,000
Allegiant Air	$	63,678,270
American Airlines Inc.	$	(1,965,101,140)
American Eagle Airlines Inc.	$	13,524,570
Colgan Air	$	(8,973,770)
Comair Inc.	$	(61,211,000)
Compass Airlines	$	7,726,750
Continental Air Lines Inc.	$	568,875,000
Delta Air Lines Inc.	$	978,695,000
Executive Airlines	$	9,498,030
ExpressJet Airlines Inc.	$	(31,900,200)
ExpressJet Airlines Inc. (1)	$	(28,348,870)
Frontier Airlines Inc.	$	(72,054,940)
GoJet Airlines, LLC d/b/a United Express	$	5,043,260
Hawaiian Airlines Inc.	$	7,967,110
Horizon Air	$	(10,135,000)
JetBlue Airways	$	86,250,590
Lynx Aviation d/b/a Frontier Airlines	$	(894,370)
Mesa Airlines Inc.	$	5,506,440
Mesaba Airlines	$	(12,088,020)
Pinnacle Airlines Inc.	$	(7,993,650)
PSA Airlines Inc.	$	(9,305,460)
Republic Airlines	$	26,680,500
Shuttle America Corp.	$	29,427,060
SkyWest Airlines Inc.	$	36,557,000
Southwest Airlines Co.	$	200,662,000
Spirit Air Lines	$	67,340,180
Sun Country Airlines d/b/a MN Airlines	$	4,328,720
United Air Lines Inc.	$	282,080,860
US Airways Inc.	$	180,375,870
USA 3000 Airlines	$	(9,844,550)
Virgin America	$	(100,402,880)
Total	**$**	**501,416,780**

Cargo		Net Income
ABX Air, Inc.	$	5,379,700
Aerodynamics Inc.	$	(1,248,500)
Air Transport International	$	(12,767,520)
Aloha Air Cargo	$	69,660
Amerijet International	$	899,820
Asia Pacific	$	578,660
Astar USA, LLC	$	14,362,340
Atlas Air Inc.	$	80,251,520
Avjet Corporation	$	(752,000)
Capital Cargo International	$	(8,045,940)
Casino Express	$	(106,650)
Centurion Cargo Inc.	$	(4,190,690)
Evergreen International Inc.	$	(13,445,420)
Federal Express Corporation	$	818,205,000
Florida West Airlines Inc.	$	842,780
Kalitta Air LLC	$	44,517,060
Lynden Air Cargo Airlines	$	18,291,360
Miami Air International	$	2,358,690
National Air Cargo Group, Inc. d/b/a Murray Air	$	(19,408,800)
North American Airlines	$	(23,615,910)
Northern Air Cargo Inc.	$	3,678,180
Omni Air Express	$	24,943,700
Polar Air Cargo Airways	$	-
Ryan International Airlines	$	2,890,710
Southern Air Inc.	$	(113,045,770)
Tatonduk Outfitters Limited d/b/a Everts Air Alaska	$	5,087,990
United Parcel Service	$	130,165,900
USA Jet Airlines Inc.	$	3,790,580
Vision Airlines	$	(16,765,760)
World Airways Inc.	$	(51,973,840)
Total	**$**	**890,946,850**

			% Air Industry
Passenger Total	$	501,416,780	**36%**
Cargo Total	$	890,946,850	**64%**
Grand Total	**$**	**1,392,363,630**	