Original Article

Polychlorinated biphenyl and heavy metal exposures among fishermen in the Straits of Malacca: neurobehavioural performance

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The aim of this study was to determine the level of exposure to polychlorinated biphenyls (PCBs) and selected heavy metals among fishermen via dietary intake of fish and other seafood from the eastern coast along the Straits of Malacca. This study determined the neurobehavioural performances (based on neurobehavioural core test battery scores) of the fishermen and evaluated the correlations between scores of neurobehavioural core test battery and exposure factors. Ninety fishermen participated in the study. The total fish intakes of the fishermen were measured using a set of food frequency questionnaires. The PCBs contents in the seafood samples ranged between 0.2 and 0.6 pg/g fresh sample. The concentrations of mercury (Hg), arsenic (As), cadmium (Cd), and lead (Pb) in the seafood samples were 1.1-5.4, 0.3-4.4, 0.6-36.1, and 0.02-0.3 μg/g fresh sample, respectively. The PCBs, Hg, As, Cd, and Pb exposures of the fishermen was estimated to be 2.8, 0.02, 4.5, 0.09, and 0.5 pg/kg body weight/day, respectively. PCB and heavy metal exposures through dietary intake of fish and seafood were within the tolerable daily limits. The results of neurobehavioural core test battery revealed that the neurobehavioural performances of the fishermen were not affected due to PCB and heavy metal intoxication. No correlations were found between the exposure and neurobehavioural performance among the fishermen. These data are useful for policy makers to assure the safety and quality of seafood in relation to sea pollution. Although the levels of exposure were low, periodic assessment of the quality of fish and fish products is required due to the polluted seawater.

Key Words: fish, fishermen, heavy metal, neurobehavioural, polychlorinated biphenyl

INTRODUCTION

The choices of fish consumed daily vary from one person to another due to the fish availability in fish markets. Different types of fish contain slightly different amounts of nutrients and serve as excellent sources of protein, fat, vitamins, and minerals. In addition to nutrients, fish may also contain harmful elements. These elements are known to be stored in the fatty tissue of the fish.[1-3] The consumption of fish may be prone to a high risk of potential contamination. Thus, it is crucial to investigate the consequences of possible contaminants, such as polychlorinated biphenyl (PCB) and heavy metal exposures, in the Malaysian community. The presence of chemical contaminants in seafood has been closely monitored by most countries because these contaminants may be deposited in the human body via food consumption, particularly from marine fish. The potential hazards for humans of heavy metal contaminants in fish and other seafood include neurobehavioural disorders.

Food intake is the primary route of exposure to environmental pollutants for most non-occupationally exposed individuals.[4] The contribution of fish, fish products, and seafood may exceed 90% of total exposures to PCBs and other chemical contaminations.[5] Fishermen are at risk of exposure to higher levels of PCBs and heavy metals than the members of other professions due to the more frequent consumption of seafood. The high PCB exposure

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Manuscript received 13 August 2014. Initial review completed 01 September 2014. Revision accepted 19 September 2014.
doi: 10.6133/apjcn.2015.24.3.06

in Swedish fishermen was due to the high intake of fish.[6] The groups of people from different continents who frequently consumed large quantities of fish have significantly high risks of PCB and dioxin/furan intoxication.[7] Another study in Taiwan revealed a significant positive association (multivariate-adjusted) between the level of serum chlorinated compound and fish intake among the studied population above 45 years old.[8] In addition, heavy metals, such as mercury (Hg), lead (Pb), and cadmium (Cd) are considered the most toxic metals, which are also deleterious to human health.[9]

Neurobehavioural core test battery (NCTB) has been used to determine the adverse effects of fish consumption on neurobehavioural disorders among fishermen that might have been exposed to PCBs and heavy metals in seafood. The NCTB is a powerful tool for assessing more subtle behavioural impairments of an individual who has been exposed to environmental pollutants in the absence of clinical signs. The NCTB can also be used to assess behavioural outcomes by measuring cognitive functioning, such as visuomotor skills, the ability to sustain information and higher-level information on learning and memory.[10,11] NCTB is a useful tool to evaluate the neurobehavioural performances among fishermen who consumed fish and other seafood obtained from the Straits of Malacca. It is also a valuable tool to evaluate the neurobehavioural performances in relation to PCB and heavy metal exposures. This study also determined the correlation between NCTB scores and exposure factors among the fishermen.

METHODS

PCBs and heavy metals in seafood sample

As reported in one of our previous studies, all the samples were collected from 10 identified fish landing sites of the eastern coast along the Straits of Malacca.[12] Briefly, the fish samples were washed and filleted while the muscle tissues of shellfish were washed and stored at –20℃ before extraction of fat. Internal organs, head, fins, and scales of all fish were discarded. All non-edible parts of cuttlefish, prawn, and cockles were also removed. The fillets of fish and the muscle tissues of shellfish were determined for the concentrations of PCBs and heavy metals.[12,13]

Before the analysis of heavy metals, the seafood samples were dried for 72 h using an air oven (60-70℃) and ground into powder using a mortar. The samples (0.5 g) were digested using 5 mL of 65% nitric acid, kept for one day in room temperature (25℃), and heated at 60-80℃ for 3 h. Based on the method described previously, the fat of all fresh samples that had been pre-spiked with 4937 PCBs internal standard was extracted by applying accelerated solvent extraction.[12] PCBs and heavy metals in the seafood samples were determined using a high-resolution gas chromatography-mass spectrometer and inductively coupled plasma optical emission spectrophotometer,[12,13] respectively. The selected heavy metals were Hg, arsenic (As), Cd and Pb.

Study design and population studied

A cross-sectional study was designed to evaluate neurobehavioural disorders of fishermen recruited from a randomly selected fishing village of the eastern coast along the Straits of Malacca. The subjects were recruited from the fishing village based on a simple random sampling method. Fishermen were chosen from the selected community due to their higher consumption of seafood than the other groups of communities living in the area. In fact, Malaysian fishermen who live beside the sea consumed greater amounts of seafood than in those communities living in the rural area.[14] Informed consent was obtained from the fishermen who agreed to participate in this study. The study design was approved by the ethical committee of the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia [UPM/FPSK/PADS-/T7-MJKEtikaPer/F01-JPD_JAN(10)03].

Data collection

The recruited fishermen were given a set of questionnaires consisting of four sections, namely, sociodemographics, individual health status, lifestyles and food frequency questionnaire (FFQ). The NCTB was used to evaluate the neurobehavioural performances of the fishermen. The entire procedure took approximately one hour per fisherman.

Administration of FFQ was done by interviewing the fishermen in regard to the amount, the portion size (small, medium, or large), and the average intake in a year (never, per day, per week, per month and per year) of 12 types of fish and three other sea foods. Based on the FFQ, the amount of total intake in one day was calculated based on the following equation:

$$\text{Total fish intakes (g) per day} = \text{Frequency of intake} \times \text{Weight of fish in one serving}$$

The PCB and heavy metal exposures of the fishermen through consumptions of fish and other seafood were calculated based on the following equation:

$$\text{Mean exposure per day} = \frac{\text{Amount of seafood consumed (g per day)} \times \text{Concentration of PCB or heavy metal (per g)}}{\text{Individual body weight (kg)}}$$

The NCTB is a validated and standardised psychological test battery that has been advocated by the World Health Organization (WHO), and it is considered transcultural.[10] The NCTB constitutes seven types of test, namely, Benton visual retention test, digit span test, digit symbol test, pursuit aiming test, Santa Ana manual dexterity test, simple reaction timer test, and trail making test. Table 1 summarises the types of NCTB test and their function domains.

Benton visual retention test

Benton visual retention test was used to measure the ability of the recruited fishermen to organise geometrical patterns in space and memorise the patterns. The fishermen were asked to visualise a drawing composed of geometrical patterns for 10 sec. Then, they were required to recognise and choose the same pattern shown earlier. The number of patterns correctly identified by the fishermen was counted as their score for this test.

Digit span test

Digit span test was used to measure the short-term memory and the attention of the recruited fishermen. The fishermen were required to repeat the sequence of numb-

Table 1. Functional domains of neurobehavioural core test battery[10]

Type of test	Functional domain
Digit symbol	Motor speed, visual scanning and working memory
Digit span	Short-term memory and attention
Santa Ana dexterity	Motor speed and coordination
Benton visual retention	Visual perception and memory
Pursuit aiming	Fine motor control and motor steadiness
Trail making	Attention, visual scanning and processing speed
Simple reaction timer	Attention and response speed

ers after the researcher read the number sequence aloud. They were also required to repeat forward for the "Forward Digits" test and to repeat backward for the "Backward Digit" test. The score was calculated as the total numbers of correct sequences for each fisherman.

Digit symbol test

Digit symbol test was used to measure the perceptual motor speed that required learning of associations. The fishermen were presented with a key at the top of the page with numbers 1 to 9, and their respective matching symbols displayed. They were required to fill the blank squares with the symbol paired to the corresponding digits as fast as possible within 90 sec. The number of correct symbols was considered the score for this test.

Pursuit aiming test

Pursuit aiming test was used to measure the ability of the recruited fishermen to make fast and accurate movement using their hands. The fishermen were instructed to place a dot inside each circle following the pattern given on a sheet as rapid as possible within 60 sec. Excluding the outliers, the number of dotted circles was considered the score for this test.

Santa ana manual dexterity test

Santa Ana manual dexterity test was used to measure the speed of the recruited fishermen in performing a task using their hands, which required dexterity speed and eye-hand coordination. The fishermen were given a rectangular board with pegs that arranged in four rows. They were asked to rotate the peg through 180 degrees in 30 sec. The test was repeated for the preferred and non-preferred hands. The number of rotated pegs was considered the score for this test.

Trail making test

Trail making test was used to measure the visual motor tracking and visual scanning of the recruited fishermen, which also required attention. The test had two parts; each consisted of 25 circles distributed throughout a sheet of paper. In the trial A, the fishermen were asked to draw a line connecting the circles in numerical sequences as fast as possible. The circle consisted number 1 to number 25. Trial B was different from trial A, in which the circles contained number 1 to number 13 and letter A to letter L. They were also required to connect the circles between the numbers and the letters in an ascending sequence. The test was scored based on the total numbers of attempt required to complete these trials.

Simple reaction time test

Simple reaction time test was used to measure the response speed of the recruited fishermen. The test required a sustained attention of the fishermen. The fishermen were required to provide the fastest responses after the researcher pressed a light button. When the green light flashed, they were required to provide the fastest response. But, when the red light appeared, the fishermen were required to be still. The computed mean of the response time for the three trials was considered the score for this test.

Statistical analyses

Descriptive statistics, including frequencies, means and standard deviations were used to describe the dietary variables. Spearman's rho test was used to determine the correlations between exposure factors and NCTB scores. Multivariate analysis of variance (MANOVA) was applied in adjusting for confounders. The level of significant was set at $p<0.05$.

RESULTS AND DISCUSSION

Sociodemographic characteristics

The frequency distributions of the sociodemographic characteristics of the recruited fishermen are shown in Table 2. The mean age of the fishermen was 47±11 years old. The majority of them were Malay (55.6%), followed by Chinese (43.3%) and Indian (1.1%). The mean household income of the fishermen was RM1194±720, which ranged between RM99 and RM4000. Besides, the mean working hours of the fishermen was 39.8±16.0 h per week, and 91% of them had more than 15 years of working experience as a fisherman. Moreover, the majority of the fishermen were smokers (55.5%) and approximately 14.4% of them consumed alcohol.

PCB and heavy metal exposures

Based on the results obtained from the past findings, the selected fish and other seafood sold in the markets of the west-coast of Peninsular Malaysia were contaminated with PCBs and heavy metals.[12,13,15] The fish and other seafood samples had low levels of PCBs and heavy metals (Table 3). The fish and shellfish were caught by the fishermen who settled at the eastern coastal areas along the Straits of Malacca. The fish were large-scale tongue sole (*Cynoglossus arel*), Japanese threadfin bream (*Nemipterus japonicus*), grey eel-catfish (*Plotosus* sp.), long-tailed butterfly ray (*Gymnura* sp.), six-bar grouper (*Epinephelus sexfasciatus*), Malabar red snapper (*Lutjanus argentimaculatus*), hardtail scad (*Megalaspis cordyla*), silver pomfret (*Pampus argenteus*), dorab wolf-herring

(*Chirocentrus dorab*), Spanish mackerel (*Scomberomorus guttatus*), Indian mackerel (*Rastrelliger kanagurta*) and fourfinger threadfin (*Eleutheronema tetradactylum*). The other seafoods were cuttlefish (*Sepia officinalis*), prawn (*Metapenaeus affinis*) and cockles (*Anadara granosa*).

Among the tested fish, grey eel-catfish and large-scale tongue sole had the highest total PCB contents, followed by six bar grouper, long-tailed butterfly ray, Malabar red snapper and Japanese threadfin bream (Table 3). The cockles and cuttlefish contained even higher total PCBs than the fish and prawn.[12] All fish tested had low heavy metal contents, with some exceptions (Table 3). In a previous study, the reported concentration of Cd in cockles purchased from a Malaysian market was 36.1 μg/g fresh weight.[13] The cockles have ten times higher level of Cd than in most of the tested fish and shellfish. However, the high concentration of Cd in cockles is still permitted in Malaysia. The tested fish and other seafood had low concentrations of heavy metals.

Table 4 depicts the values of PCB and heavy metal exposures via intake of fish and other seafood among the fishermen. The mean level of PCB exposure among the fishermen was 2.8 pg/kg body weight (BW) per day, while the highest level of As exposure was 4.5 μg/kg BW/day. The data also showed that the mean levels of PCB and heavy metal exposures among the fishermen were below the tolerable permitted limit.

A previous study had shown that the average intake of fish for a person weighing 60 kg should be not more than 30 g/day to avoid excessive accumulation of toxicants in the body.[16] The level of PCB exposure that was calculated for this study, 2.8 pg PCB-toxic equivalency factor (TEQ) or pg/kg BW/day, was lower than the levels reported in Finland (43 pg PCB-TEQ) and Spain (31.8 pg PCB-TEQ).[17,18] The level of dietary PCB exposure (0.06-0.37 pg/kg BW/day) reported by one of the past studies also showed a lower level of PCB exposure than the level calculated for this study.[19] The low PCB exposure might due to the low degree of contamination in the foods (animal-based food originated from China). Moreover, the differences in the dietary intake for these countries are most likely due to the specific dietary habits. For instance, in

Table 2. Sociodemographic characteristics of the fishermen

Characteristics	*n*=90 (%)	Mean (SD)	Range
Age (years)		47 (10.6)	23-71
Weight (kg)		69.7 (15.2)	42.8-118
Race		–	–
Malay	50 (55.6)		
Chinese	39 (43.3)		
Indian	1 (1.1)		
Household income (RM)		1,194 (720)	99-4,000
Working experience (years)		–	–
10-15	9 (8.9)		
>15	82 (91.1)		
Working hours (h/week)		39.8 (16.0)	6-120
Smoking		–	–
Smoker	50 (55.5)		
Non-smoker	34 (37.7)		
Already quit	6 (6.7)		
Alcohol consumption		–	–
Yes	13 (14.4)		
Non	75 (83.3)		
Already quit	2 (2.2)		

SD: standard deviation. The values are presented as mean (SD). Number of fishermen recruited, *n*=90.

Table 3. Concentrations of polychlorinated biphenyls (PCBs) and heavy metals in selected fish and other seafood

Type of sample	Total PCBs (pg/g)	Hg (μg/g)	As (μg/g)	Cd (μg/g)	Pb (μg/g)
Large-scale tongue sole	1.7	2.7	0.8	1.2	0.1
Japanese threadfin bream	0.7	5.4	1.2	0.8	0.3
Grey eel-catfish	1.8	2.1	1.0	1.6	0.1
Long-tailed butterfly ray	0.7	4.7	4.4	2.4	0.1
Six-bar grouper	0.9	3.3	0.4	0.6	0.02
Malabar red snapper	0.7	3.8	0.4	3.6	0.3
Hardtail scad	0.2	3.2	0.8	2.0	0.2
Silver pomfret	0.2	1.5	0.6	2.4	0.2
Dorab wolf-herring	0.2	5.4	0.8	0.8	0.07
Spanish mackerel	0.3	2.1	0.9	1.2	0.03
Fourfinger threadfin	0.2	2.1	0.7	1.7	0.05
Indian mackerel	0.2	1.1	0.3	0.9	0.09
Cuttlefish	2.1	1.7	0.7	4.6	0.2
Prawn	0.7	2.1	1.0	2.1	0.2
Cockles	2.6	4.8	0.8	36.1	0.2

The contents of total PCBs and heavy metals in the fish and other seafood were obtained from previous literatures.[12,13,15] The concentrations of PCBs and heavy metals in the samples were expressed as per gramme wet weight.

Table 4. Dietary exposures to polychlorinated biphenyls and heavy metals among the fishermen

Type of contaminant	Mean concentration (per kg BW per day)	Recommended level (per kg BW per day)[20]
PCBs (pg)	2.8±0.3	1-4
Hg (μg)	0.02±0.001	0.7
As (μg)	4.5±0.4	-
Cd (μg)	0.09±0.01	1
Pb (μg)	0.5±0.04	5

PCBs: polychlorinated biphenyls; Hg: mercury; As: arsenic; Cd: cadmium; Pb: lead; BW: body weight. The mean concentration was expressed as mean±standard deviation.

Table 5. Neurobehavioural core test battery scores among the fishermen

Type of test and score[10]	Number of fishermen (%)	Mean (SD)	Range
Benton visual		52.2 (9.8)	30-70
≤30 points	3 (3.3)		
>30 points	87 (96.7)		
Digit span forward		53.5 (3.7)	46-62
≤30 points	0		
>30 points	90 (100)		
Digit span backward		46.5 (3.7)	38-54
≤30 points	0		
>30 points	90 (100)		
Digit symbol		50.4 (9.8)	29-77
≤30 points	2 (2.2)		
>30 points	88 (97.8)		
Santa Ana dominant hand		46.6 (4.8)	27-64
≤30 points	1 (1.1)		
>30 points	89 (98.9)		
Santa Ana non-dominant hand		47.1 (3.9)	28-55
≤30 points	1 (1.1)		
>30 points	89 (98.9)		
Simple reaction time		49.2 (9.8)	28-77
≤30 points	2 (2.2)		
>30 points	88 (97.8)		
Pursuit aiming test		50.2 (9.1)	31-86
≤30 points	0		
>30 points	90 (100)		
Trail making test		128 (57.4)	27-336
≤129 points	54 (60.0)		
>129 points	36 (40.0)		

NCTB: neurobehavioural core test battery; SD: standard deviation. Score of more than 30 points indicates great performance for all the tests, except trail making test. Score of equal to or less than 129 points indicates great performance for trail making test.

the Nordic countries, such as Finland, the high consumption of high-fat fish, such as herring and salmon, could be one of the factors for the high exposure to contaminants.[21]

Neurobehavioural performances of the fishermen

Table 5 shows the distribution of the fishermen based on the calculate standard scores for the NCTB-based tests. The results showed that most of the standard scores obtained from the tests were above 30 points (cut-off point). However, for trail making test, the cut-off point was 129 points, which was based on the normative data obtained from this study.[22]

Based on the NCTB-based tests, 97.9-98.9% of the recruited fishermen scored more than 30 points. The scores indicated that the neurobehavioural performances of the fishermen were good. The results showed that the mean score of the digit span forward test (53.5 points) was higher than the mean score (49.6 points) of the workers who had been exposed to lead toxicity.[23] In the same study, the mean scores for the Santa Ana preferred hand test (25.1 points) and the non-preferred hand test (22.6 points) were lower than the mean scores calculated from this study. Therefore, the results clearly indicated that the neurobehavioural performances of the recruited fishermen were not affected by PCB and heavy metal toxicities.

The results obtained from the digit span forward, digit span backward and pursuit aiming tests also showed that all recruited fishermen (100%) had calculated scores of more than 30 points. This indicated that the fishermen have a good ability concerning short-term memory, attention, steadiness, control, physical speed, visual scanning and working memory. On the other hand, the scores of Benton visual test for 96.7% of the fishermen were above 30 points, and the mean score was 52.2 points. The results showed that there were only three of them had low scores for memorising the picture. Besides, the recruited fishermen had a calculated mean score of 49.2 points for the simple reaction timer test, where 97.8% of them showed good performance for speed and attention.

The positive results for the neurobehavioural tests could be probably due to the low PCB and heavy metal exposures of the fishermen through intakes of fish and other seafood. Since neurobehavioural performance is closely associated with the high intakes of PCBs and heavy metals,[24] a low dietary intake of these environmental pollutants helps in lowering the incidence of neurotoxicity. Moreover, PCBs and heavy metals are neurotoxic to humans, particularly children, and may affect their psychological, intellectual and learning performances.[25]

Correlation analyses

Table 6 shows the correlations between neurobehavioural performances (NCTB scores) and sociodemographic characteristics (exposure factors), as well as dietary exposures to PCBs and heavy metals. After controlled for possible confounders (age group, level of exposure time, smoking habit and alcohol consumption) using MANOVA, the Wilks' Lambda test revealed a significant main effect for age groups (F=1.51, p<0.05). The MANOVA results showed that the scores for digit symbol test (F=5.73, p<0.001) and trail making test (F=5.11, p<0.01) were significantly different among different age groups.

Age and neurobehavioural performances

Age was the major predictor for finger tapping performance (preferred and non-preferred trials), symbol digit and serial digit learning tests. The results obtained from the correlation analysis showed that the scores for five out of seven of the neurobehavioural tests were significantly associated with age (Table 6). The tests were Benton visual test, digit symbol test, pursuit aiming test, simple reaction time and trail making test. The scores for all these tests showed negative correlations, except the score of trail making test. The correlation analysis showed a moderate positive correlation (r=0.44, p<0.001) between age group and score for trail making test. After adjusted for confounders, only the scores for digit symbol test and trail making test were significantly correlated with age group. The finding of this study is supported by the observation that aged populations have decreased neurobehavioural performance.[26] Based on the finding reported in a previous epidemiological study, a correlation found between neurobehavioural performance and age suggests that age may affect work performance.[27]

Level of exposure time and neurobehavioural performances

Among the NCTB scores, there was a low positive correlation (r=0.23, p<0.05) between the level of exposure time and score for Benton visual test. However, after adjustment for possible confounders, the test score was not affected by the level of exposure time. Benton visual test indicated the ability of visual perception and memory among the recruited fishermen. Although the finding showed no consistent correlation between the level of exposure time and neurobehavioral performance among the fishermen, working longer hours under the hot sun might affect the visual performance of fishermen. In US, increasing numbers of working years on agricultural sites have been linked to low neurobehavioural performances.[28] Individuals who exposed to pesticide for more than ten years also had lower performances for the measures of perception and visuospatial processing than the other working years.[29] Moreover, the greatest decrease in cognitive and psychomotor functions has been observed after 10 or more years of work on farms.[28]

Lifestyle and neurobehavioural performances

In this study, no significant correlations were found between the NCTB scores and lifestyles among the fishermen, except the Santa Ana dominant hand test. The result showed that there was a positive weak correlation (r=0.21 and p<0.05) between smoking habit and score for Santa Ana dominant hand test. However, the recruited fishermen were observed by the research team members as having poor performances for physical speed and coordination. The past study has also shown a positive correlation between smoking habits and Santa Ana preferred hand performance among individuals occupationally not exposed to neurotoxic chemicals.[30]

Dietary exposures and neurobehavioural performances

Based on the results obtained, there were no significant correlations between dietary exposures and NCTB scores. The lack of relationships between the dietary exposures and neurobehavioural performances are probably due to the low intakes of seafood among the recruited fishermen. This result is further supported by the observation from a past study that no relationship was found between diet and neurobehavioural performance among the farm workers in the highland Ecuador.[31]

Due to the exposure to low levels of PCBs and heavy metals, the recruited fishermen should have good neurobehavioural performances. In addition to the consumption of contaminated seafood, heavy metal contamination was also determined in drinking water.[32,33] In Malaysia, drinking water contamination seldom occurs. The levels of heavy metals determined in the bottled drinking water, mineral water, and tap water that were obtained from Peninsular Malaysia were below the national and international standard limits.[34] Therefore, this finding indicated that the recruited fishermen have a good performance on short-term auditory memory. Any contaminants will affect the human blood system and may cause other related diseases, whereas a high level of heavy metal exposure may also cause alterations in the nervous system, renal failure and anaemia. Moreover, heavy metal exposure could affect the neurophysiological performance of the fishermen.

Conclusion

The consumption of fish and other seafood obtained from the Straits of Malacca may not contribute to any neurobehavioural deficit in the fishermen. Ageing was closely related to a reduction in the ability to perform some neurobehavioural tasks. Long work hours might cause neurobehavioural disorders, but smoking and drinking alcohol do not recognisably affect the neurobehavioural performances. Although a high intake of seafood contaminated with environmental pollutants can endanger human health, exposures to PCBs and heavy metals via seafood consumption are not adequate to cause any neurobehavioural changes in the fishermen.

Table 6. Correlations between NCTB scores and exposure factors

	Benton visual	Digit span forward	Digit span backward	Digit symbol	Pursuit aiming test	Santa Ana dominant hand	Santa Ana non-dominant hand	Simple reaction time	Trail making test
Age group	-0.23*	-0.10	0.10	-0.49**	-0.31**	-0.03	-0.07	-0.29*	0.44**
Level of exposure time	0.23*	-0.16	0.16	0.03	0.13	-0.05	-0.02	-0.01	-0.13
Smoking habit	0.02	-0.12	0.12	-0.11	-0.03	0.21*	-0.001	-0.02	0.02
Alcohol consumption	-0.08	-0.03	0.03	0.08	0.11	-0.09	0.12	0.02	0.12
PCBs	0.07	-0.01	0.01	0.08	-0.06	0.03	-0.18	-0.05	0.02
Hg	0.09	0.04	-0.04	0.12	-0.02	0.07	-0.13	-0.06	0.03
Pb	0.07	0.03	-0.03	0.08	-0.04	0.04	-0.16	-0.001	0.01
Cd	-0.01	0.05	-0.05	0.09	-0.03	0.04	-0.17	-0.04	0.02
As	0.13	0.05	-0.05	0.1	-0.05	0.02	-0.17	-0.08	0.08

NCTB: neurobehavioural core test battery; PCBs: polychlorinated biphenyls; Hg: mercury; Pb: lead; Cd: cadmium; As: arsenic. **Significant correlation at $p<0.01$ (2-tailed) and *significant correlation at $p<0.05$ (2-tailed).

ACKNOWLEDGEMENTS
We thank the management and staffs of the Fisheries Development Authority of Malaysia (LKIM) and the Area Fishermen's Association (PNK) for their assistance in the sampling of fresh fish and other seafood, as well as for the recruitment of subjects.

AUTHOR DISCLOSURES
The authors declare no conflict of interest. The study was financially aided by the research grant (Vote No. 5450400) from the Ministry of Science, Technology and Innovation, Malaysia.

REFERENCES
1. Siscovick DS, Raghunathan TE, King I, Weinmann S, Wicklund KG, Albright J et al. Dietary intake and cell membrane levels of long-chain n-3 polyunsaturated fatty acids and the risk of primary cardiac arrest. JAMA. 1995; 274:1363-7. doi: 10.1001/jama.274.17.1363.
2. Daviglus ML, Stamler J, Orencia AJ, Dyer AR, Liu K, Greenland P, Walsh MK, Morris D, Shekelle RB. Fish consumption and the 30-year risk of fatal myocardial infarction. N Engl J Med. 1997;336:1046-53. doi: 10.1056/NEJM199704103361502.
3. Domingo JL, Bocio A, Falcó G, Llobet JM. Benefits and risks of fish consumption: part I. A quantitative analysis of the intake of omega-3 fatty acids and chemical contaminants. Toxicology. 2007;230:219-26. doi: 10.1016/j.tox.2006.11.054.
4. Harrison N, Wearne S, Gem MDM, Gleadle A, Starting J, Thorpe S et al. Time trends in human dietary exposure to PCDDs, PCDFs and PCBs in the UK. Chemosphere. 1998; 37:1657-70. doi: 10.1016/S0045-6535(98)00232-X.
5. Bocio A, Domingo JL. Daily intake of polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/PCDFs) in foodstuffs consumed in Tarragona, Spain: a review of recent studies (2001-2003) on human PCDD/PCDF exposure through the diet. Environ Res. 2005;97:1-9. doi: 10.1016/j.envres.2004.01.012.
6. Svensson BG, Mikoczy Z, Strömberg U, Hagmar L. Mortality and cancer incidence among Swedish fishermen with a high dietary intake of persistent organochlorine compounds. Scand J Work Environ Health. 1995;21:106-15. doi: 10.5271/sjweh.17.
7. Domingo JL, Bocio A. Levels of PCDD/PCDFs and PCBs in edible marine species and human intake: a literature review. Environ Int. 2007;33:397-405. doi: 10.1016/j.envint.2006.12.004.
8. Chen HL, Su HJ, Lee CC. Association between tofu intake and serum polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) in the elderly Taiwanese. Environ Int. 2007;33:265-71. doi: 10.1016/j.envint.2006.09.019.
9. Quandt SA, Jones BT, Talton JW, Whalley LE, Galván L, Vallejos QM et al. Heavy metals exposures among Mexican farm workers in eastern North Carolina. Environ Res. 2010; 110:83-8. doi: 10.1016/j.envres.2009.09.007.
10. World Health Organization (WHO). Operational guide for the WHO neurobehavioral core test battery. Geneva: World Health Organization; 1986.
11. Krieg Jr EF, Chrislip DW, Letz RE, Otto DA, Crespo CJ, Stephen Brightwell W, Ehrenberg RL. Neurobehavioral test performance in the third National Health and Nutrition Examination Survey. Neurotoxicol Teratol. 2001;23:569-89. doi: 10.1016/S0892-0362(01)00177-5.
12. Alina M, Azrina A, Mohd Yunus AS, Mohd Zakiuddin S, Mohd Izuan Effendi H, Muhammad Rizal R. Heavy metals (mercury, arsenic, cadmium, plumbum) in selected marine fish and shellfish along the Straits of Malacca. Int Food Res J. 2012;19:135-40.
13. Mohamad A, Azlan A, Razman MR, Ramli NA, Latiff AA. Polychlorinated biphenyls (PCBs) concentration in demersal fish and shellfish from West Coast of Peninsular Malaysia. J Food Agric Environ. 2013;11:1094-8.
14. Norimah AK, Safiah M, Jamal K, Siti Haslinda, Zuhaida H, Rohida S et al. Food consumption patterns: findings from the Malaysian Adult Nutrition Survey (MANS). Mal J Nutr. 2008;14:25-39.
15. Nurul Nadiah MN, Azlan A, Razman MR, Ramli NA, Latiff AA. PCDDs and PCDFs in pelagic fish along the Straits of Malacca. Pertanika J Trop Agric Sci. 2012;35:779-94.
16. Horvat M, Nolde N, Fajon V, Jereb V, Logar M, Lojen S et al. Total mercury, methylmercury and selenium in mercury polluted areas in the province Guizhou, China. Sci Total Environ. 2003;304:231-56. doi: 10.1016/S0048-9697(02)00572-7.
17. Kiviranta H, Hallikainen A, Ovaskainen ML, Kumpulainen J, Vartiainen T. Dietary intakes of polychlorinated dibenzo-p-dioxins, dibenzofurans and polychlorinated biphenyls in Finland. Food Addit Contam. 2001;18:945-53. doi: 10.1080/02652030110057134.
18. Bocio A, Domingo JL, Falcó G, Llobet JM. Concentrations of PCDD/PCDFs and PCBs in fish and seafood from Catalan (Spain) market: estimated human intake. Environ Int. 2007;33:170-5. doi: 10.1016/j.envint.2006.09.005.
19. Li JG, Wu YN, Zhang L, Zhao YF. Dietary intake of polychlorinated dioxins, furans and dioxin-like polychlorinated biphenyls from foods of animal origin in China. Food Addit Contam. 2007;24:186-93. doi: 10.1080/02652030600970366.
20. Van den Berg M, Birnbaum LS, Denison M, De Vito M, Farland W, Feeley M et al. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicol Sci. 2006;93:223-41. doi: 10.1093/toxsci/kfl055.
21. Storelli MM, Barone G, Perrone VG, Giacominelli-Stuffler R. Polychlorinated biphenyls (PCBs), dioxin and furans (PCDD/Fs): occurrence in fishery products and dietary intake. Food Chem. 2011;127:1648-52. doi: 10.1016/j.foodchem.2011.02.032.
22. Tombaugh TN. Trail making test A and B: normative data stratified by age and education. Arch Clin Neuropsychol. 2004;19:203-14. doi: 10.1016/S0887-6177(03)00039-8.
23. Mazrura S, Noor Hassim I. Neurobehavioral performance among exposed workers in Malaysia: an early detection of lead toxicity. Malaysia: National Institute of Occupational Safety and Health; 2005.
24. Weihe P, Grandjean P, Debes F, White R. Health implications for Faroe Islanders of heavy metals and PCBs from pilot whales. Sci Total Environ. 1996;186:141-8. doi: 10.1016/0048-9697(96)05094-2.
25. Canfield RL, Henderson Jr CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual impairment in children with blood lead concentrations below 10 µg per deciliter. N Engl J Med. 2003;348:1517-26. doi: 10.1056/NEJMoa022848.
26. Rohlman DS, Lasarev M, Anger WK, Scherer J, Stupfel J, McCauley L. 2007. Neurobehavioral performance of adult and adolescent agricultural workers. Neuro Toxicol. 2007;28: 374-80. doi: 10.1016/j.neuro.2006.10.006.
27. Anger WK, Sizemore OJ, Grossman SJ, Glasser JA, Letz R, Bowler R. Human neurobehavioral research methods: impact of subject variables. Environ Res. 1997;73:18-41. doi: 10.1006/enrs.1997.3707.
28. Kamel F, Rowland AS, Park LP, Anger WK, Baird DD, Gladen BC, Moreno T, Stallone L, Sandler DP. Neurobehavioral performance and work experience in

Florida farmworkers. Environ Health Perspect. 2003;111: 1765-72. doi: 10.1289/ehp.6341.
29. Roldán-Tapia L, Parrón T, Sánchez-Santed F. Neuropsychological effects of long-term exposure to organophosphate pesticides. Neurotoxicol Teratol. 2005;27: 259-66. doi: 10.1016/j.ntt.2004.12.002.
30. Kim JH, Lee TK, Lee IK. Performance of the WHO NCTB (neurobehavioral core test battery) among 96 males occupationally non-exposed to neurotoxic chemicals. Korean J Aerosp Environ Med. 1999;9:313-25.
31. Berti PR, Krasevec J, Cole D. Diet inadequacies and neurobehavioural impairment in rural highland Ecuadoreans. Ottawa: Health Bridge; 2004.
32. Jane Wyatt C, Fimbres C, Romo L, Mendez RO, Grijalva M. Incidence of heavy metal contamination in water supplies in Northern Mexico. Environ Res. 1998;76:114-9. doi: 10.1006 /enrs.1997.3795.
33. Azrina A, Khoo HE, Idris MA, Amin I, Razman MR. Major inorganic elements in tap water samples in Peninsular Malaysia. Mal J Nutr. 2011;17:271-6.
34. Azlan A, Khoo HE, Idris MA, Ismail A, Razman MR. Evaluation of minerals content of drinking water in Malaysia. Sci World J. 2012;2012:403574. doi: 10.1100/ 2012/403574.

Original Article

Polychlorinated biphenyl and heavy metal exposures among fishermen in the Straits of Malacca: neurobehavioural performance

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马六甲海峡渔民的多氯联苯和重金属暴露：神经行为表现

本研究的目的是根据渔民从马六甲海峡东海岸获取的鱼和其他海鲜的膳食摄入量来确定其暴露于多氯联苯（PCBs）和选定的重金属的水平。这项研究探讨了渔民们的神经行为表现（基于神经行为核心测试分），并评估该神经行为核心测试成绩和暴露因素之间的相关性。九十渔民参与了这项研究。用食物频率问卷测量渔民们的总鱼摄入量。海鲜样品多氯联苯的含量介于 0.2 和 0.6 pg/g 新鲜样品。海鲜样品中的汞、砷、镉和铅的浓度分别为 1.1-5.4、0.3-4.4、0.6-36.1 和 0.02-0.3 μg/g 新鲜样品。渔民们的多氯联苯、汞（Hg）、砷（As）、镉（Cd）和铅（Pb）暴露估计分别为 2.8、0.02、4.5、0.09 和 0.5 pg/kg 体重/天。渔民们每日多氯联苯和重金属通过鱼和海鲜膳食摄入的暴露量均在可接受的限度内。他们的神经行为核心测试结果显示渔民们的神经行为表现不受多氯联苯和重金属中毒的影响。渔民们的神经行为表现与该暴露没有相关性。这些数据有利于政策制定者确保与海洋污染有关的海产品的安全和质量。虽然该暴露水平较低，由于海水受到污染，定期评估鱼和鱼产品质量是必要。

关键词 ：鱼、渔民、重金属、神经行为、多氯联苯