

Unwilling and Unwitting: Problems of the Thai Construction Workers Dealing with the Newly Emergent Risk of Nanomaterials

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Abstract

The construction sector is one of the major factors of economic growth in Thailand. As an industry, it provides an alternative career for almost 2 million seasonal migrants from the agricultural sector. Unfortunately, unskilled construction workers are one of the most neglected groups in Thai society, frequently assigned to work in high-risk, unsafe working conditions. They have neither the knowledge nor the bargaining power to prevent this.

This research aims to investigate the level of knowledge among construction workers on health risks posed by engineered nanoparticles (ENPs) contained in construction products such as tile grout and paint. Most ENPs are recognised by both scholars and international organisations as new carcinogenic agents, but the public still has little knowledge and even less awareness of this problem. This study conducted a survey of 1,055 construction workers in Bangkok, and the Northeast, North and Central regions of Thailand in order to reveal the level of existing knowledge of this newly emergent health risk. The findings from this study highlight a low existing knowledge of the health risks presented from daily usage of construction nanotech products among workers. However, the exposure level is rarely high. Analysis of the determinants of risk exposure reveals that age, work experience, work position and size of firm determine potential exposure of worker on health risk from ENPs.

Keywords: health risk, knowledge, construction worker, nanomaterials

Background

Thailand is a developing country with a majority of its workforce in the agricultural sector. In 1961, Thailand launched the First National Economic Development Plan (1961-1966) to provide a pathway for the country to achieve economic growth. One effect of economic growth for Thailand has been increasing urbanisation, fuelling the phenomenon of urban migration. The extension of cities has shifted large numbers of unskilled labourers from the agricultural sector to work on construction sites (National Economic and Social Development Board, 2002). Almost 2 million rural-to-urban migrants in Thailand participate in the construction industry and the majority of these workers is unskilled (National Statistical

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Office, 2006). These workers generally remain vulnerable due to their low or even lack of education, and their lack of bargaining power for proper health and safety provisions on worksites.

Technological advancement is a necessary condition for continuing economic growth in any country. Among the new technologies that have been released from the laboratory to the market, nanotechnology is expected to maximise profit in the coming world economy (Ramón, Compañó, and Hullmann, 2002). However, due to the fact that nanotechnology is dealing with materials at molecular scaled, there are some concerns about potential health hazard having on living organisms and humans. Many international and national agencies have launched nanosafety initiative program focusing on environment, health and safety (EHS) while a number of nanoproducts are still pouring into the market (Scheufele and Lewenstein, 2005; Sheetz et al., 2005; National Nanotechnology Center, 2008; Organisation for Economic Co-operation and Development, 2011; National Health Commission Office, 2011). For example, In the United States, the National Institute for Occupational Safety and Health (NIOSH) launched a process to assess the potential health hazards of nanomaterials and provide information on working safely with engineered nanomaterials while every nanomaterial had to be registered under the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) as engineered nanoparticles (ENPs) is considered as chemical component under pesticide category (National Institute for Occupational Safety and Health, 2007; Registration, Evaluation, Authorisation and Restriction of Chemicals, 2008).

The National Nanotechnology Centre, under the Ministry of Science and Technology, estimated that there are more than 30 nanotech products currently being used in the Thai construction industry (Taepakum, 2008). Any technological innovation, including nanotechnology, must be accompanied by a corresponding development of skills and knowledge. Since all innovations come with potential benefits and dangers, proper education and training are needed to minimise the risk. This is particularly true for ENPs especially in terms of nanosafety (Tran, 2005; Tanasugarn, 2007; Chuankrerkkul and Sangsuk, 2008). Yet, such a knowledge is close to non-existent among the workers, particularly among those dealing with the products on a regular basis. In fact, the terms “nanotechnology” or “nanotech products” are known among the educated elite because of their ability to better access the relevant information. But for those 2.1 million construction workers who are poorly educated and earn low wages on construction sites, the words “nanotechnology” or “nanotech products” are beyond their knowledge. As a result, they continue to expose to nanotech products through daily usage without awareness of potential risk.

The harmful effects and possible consequences of ENPs on biological systems have been mentioned in many forums. ENPs can cause cell injury by attacking DNA, proteins and membranes and can be absorbed to human body causing symptoms like inflammatory and fibrotic responses (Brown et al., 2007; Warheit et al., 2008; Joshi, 2009). Nanoproducts such as the nanosilver (nano Ag), commonly used in the coating industry, and titanium dioxide (TiO_2), commonly found in paint, are suspected of causing pulmonary impairment and function change, and damaging human lung tissue due to their carcinogenic properties (Lim et al., 2009). A study of Hsu and Chein (2007) also indicated that glazed tile TiO_2 has the highest level of ENPs emissions, especially when the product is exposed to UV light. Furthermore, a study of Lee and Alvarez (2009) supports previous concerns about potential

environmental and human health impacts of nanomaterials used in the construction industry such as respiratory damage and skin inflammation.

Regarding the uncertainty of health impacts, it remains difficult to give reliable information about nanomaterials because official health assessment of the products is still underway. This means that vulnerable people in construction workers tend to operate in high risk occupational environments with little concern being shown due to the lack of awareness. This shortage of information may lead to an over-exposure to hazardous substances.

To study the relationship between knowledge of health risks and the risk of exposure, there are two theories of behaviour employed in this study: the HBM and the Theory of Plan Behavior (TPB). For HBM factors, such as perceived susceptibility (individual perceptions of the risk and the level of knowledge about potential health impacts) and perceived barriers (individual action taken to limit the dangers of exposure) are appropriate to use as a framework for study (Becker, Drachman and Kirscht, 1974; Janz and Becker, 1984). The HBM has been widely used since 1974 for explaining individual health behaviour. Given the framework of the HBM, this study assumes that the level of knowledge of health risks (perceived susceptibility) is associated with risk of exposure (perceived barriers) to ENPs based on an assumption that higher protection from danger may be applied only when the knowledge of those dangers exist.

Theory of Planned Behavior (TPB) is a type of psychological model of health related to behavior that is widely applied in many fields including risk behavior on hazard exposure as it gives some of the best explanations of how knowledge, attitudes and perceptions relate to behavior (Grob, 1995). Knowledge and experience may also be influenced by demographics, lifestyle, self identity and social status (Sutton, 2001; Harvey et al., 2002). According to TPB, social factor such as social influence (in this case, firm size) was examined to show the influence on product usage. Workers in the larger firms could be less likely to expose to more various types of construction product due to their capability and rich information as well as well protective equipment available and stronger regulation on site comparing to small firm workers. Thus, risk exposure to ENPs may be varied according to firm characteristics.

There are currently more than 30 available construction nanotech products, among them self-cleaning coatings, mirror coatings, paint, window cleaners, and hydrophobic tile grout currently being used in Thailand. These products have been available in the Thai market for more than 5 years. This leads researchers to expect that there would be some existing experience and knowledge about how to handle nanotech products among construction workers. Thus, the aim of this study is to investigate knowledge related to health risks from nanotech products among those workers who have been exposed to engineered particles released during construction.

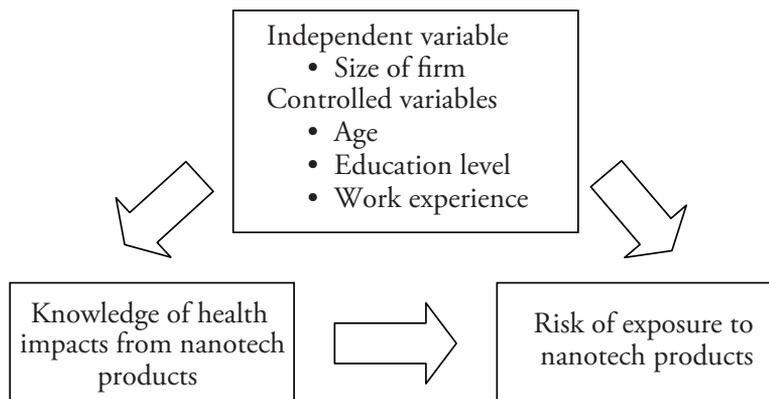
Since there are many nanomaterials in the market, this study focuses only on titanium dioxide (TiO_2) and silver nanoparticles (nano Ag) due to their status as registered carcinogens. It is hoped that findings may demonstrate the level of potential health risk behaviours, which could lead to appropriate policies for protecting workers from the possible hazards of ENPs and to promote the dissemination of information to at-risk workers. Furthermore, the findings could bring about greater public understanding of potential harm from this emerging technology. The important questions to be addressed in this study are as follows.

- (1) What is the level of existing knowledge about the health risks of inhaled nanoparticles (TiO_2 and nano Ag) among the construction workforce?
- (2) Is there any relationship between knowledge of the health impacts of ENPs and risk behaviour of construction workers in their nanoproducts usage?

Research Methodology

To examine the connection between knowledge and behaviour, the research employs Logistic Regression Analysis to explore the effects from the independent variables of demographic (age, gender) and social characteristics (education, work position, experience, etc.) of samples on the dependent variables of knowledge of health risk from the use of nanotech products. A questionnaire was employed for data collection and a reliability test was done (Cronbach Alpha = .87). This research focuses on examining two questions as shown in Figure 1. The first is whether the independent variables have a significant relationship to knowledge of health risks and also to risk of exposure on nanotech products. The second is to ascertain the connection between the knowledge of health impacts of ENPs and risk of exposure to nanotech products.

Figure 1: Connection between knowledge of health impacts from nanotech products usage and risk of exposure



The demographic variable of age is examined in relation to knowledge of health risk from ENPs in construction nanotech products as the controlled variable. Furthermore, because more complicated projects such as dams, power plants, and new rail systems normally require greater technological experience and expertise, these projects are usually undertaken by larger firms. Therefore, workers in large firms are often more experienced in high technology or the use of the most up-to-date materials in construction than those in small firms. Thus, the size of firm in this study is relevant to examining the influence of individual knowledge about risk factors from chemical substances like ENPs.

Education levels seem to have an impact on the acceptance of new technology. This may be in the sense that managers and workers who have different levels of education may have different perceptions and thoughts relating to the use of nanotech products in construction. Thus, education will be investigated as a moderator, and is expected to be a determinant toward knowledge of health risks from ENPs. Experienced managers and workers, or those with greater levels of education, would be expected to know more about the proper use of harmful materials. Experience is also an important aspect of this study since workers who have more experience with various types of materials and building technology should be more aware of the dynamics of material evolution than those with less experience.

The research assigns the sample size by exploring the population from the 3rd round of the Labor Force Survey (LFS) 2006, which showed that there were 1,608,198 persons employed in the construction industry in that year. Considering the distribution of the construction workforce followed by work position in each region, it was found that most of the skilled workers in foreman or higher positions such as engineers and architects worked in Bangkok, the central and northern regions at 45.0%, 22.4% and 12.8%, respectively. Most unskilled workers in positions lower than foreman worked in the northeastern, central and northern region at 31.6%, 24.7% and 20.2%, respectively.

Sample

This study employed purposive stratified random sampling by giving the target population's characteristic as individuals in hierarchical levels of occupation. It focused on individual unskilled workers facing technological change, and then on administrative and management levels. In the study, Bangkok and the northeast region were selected to represent Thai construction workers due to the fact that Bangkok is the major destination for rural to urban migration, while the majority of Thai construction workers originate from the northeastern region (National Statistical Office, 2006). A manager is defined as a person who has graduated at least at the diploma level. Skilled and semi-skilled workers such as engineers, architects and technicians are also defined as persons who have graduated at least at the diploma level. The category of unskilled workers comprises craftsmen and labourers who are normally less educated; some are illiterate. Division into the three groups of workers mentioned above allowed all types of workers to be selected so as to represent the proportion of all categories of workers at each hierarchical level.

A questionnaire asked for self-reporting from respondents who were able to read, while face to face interviewing was mostly conducted with construction laborers who were illiterate. The workers assessed by themselves whether or not they used nanomaterials and/or whether or not they had a risk of exposure to nanomaterials. The distribution of questionnaires was carried out by taking into account the hierarchical distribution for each firm. For example in a normal case, one manager (who had completed higher than a bachelor degree), one architect or engineer (who had completed a bachelor's degree), one foreman (who had completed a diploma), five craftsmen (who had completed certificates), two construction labourers (who had graduated at lower than certificate level) would be chosen in order to reflect the hierarchical distribution. The questionnaire survey was distributed proportionally among 110 firms. The survey was conducted between April and July 2009, with 1,055 interviews completed.

To measure the knowledge on health risk of ENPs, a series of questions to measure the worker's knowledge and later criterion-referenced test (CRT) is employed to classify respondents; those who have scores more than 60% are classified as having knowledge about health risk from ENPs, otherwise not having knowledge.

Results

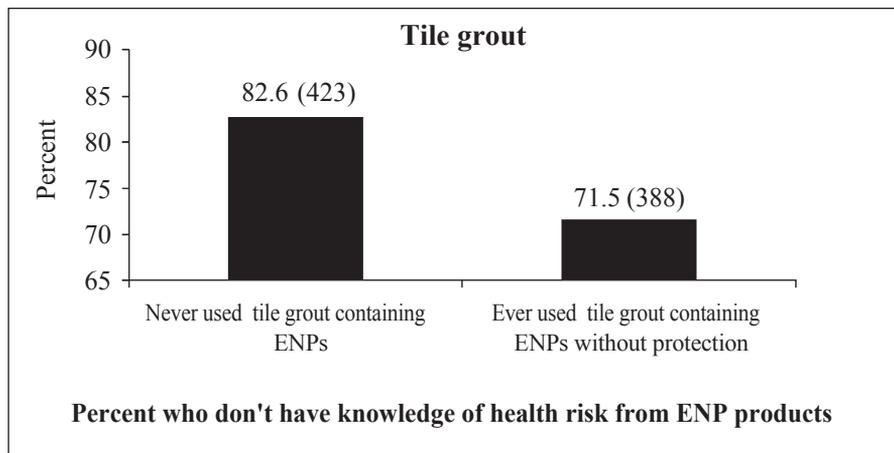
Knowledge of ENP toxicity

Most respondents (>80%) who said that they never used nanotech products also said that they did not know what nanotechnology was. Most of them had not applied any form of protective device like masks or gloves because they did not feel that they worked with any toxic chemical agent. These findings are similar to the findings of Zhu, Bartos and Porro (2004) in a European survey about the application of nanotechnology in construction. Such findings reveal the gap in knowledge among workers who are involved with nanotech products. They should be aware that unintended accidental release of ENPs from products can occur during the construction process.

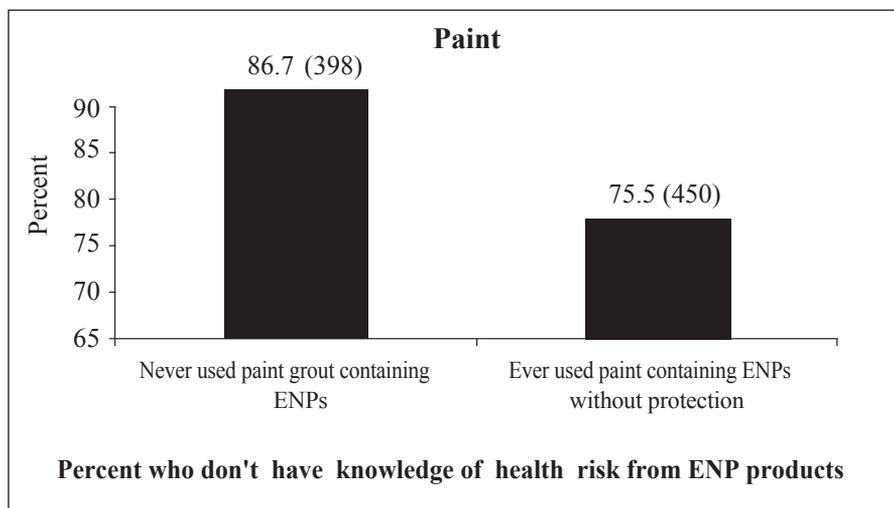
Knowledge and risk of exposure to inhaled TiO₂ and nano Ag

The descriptive analysis in Figure 2 shows the comparison of knowledge among workers; it indicated that most workers who use both tile grout and paint do not have knowledge of health risk from ENPs (>70 %). There is a relationship between knowledge of health risk and risk of exposure among workers who never/ever use construction nanotech products at statistical significant level of 0.01. The relationship between "ever use nano-paint" and having health risk knowledge is a little higher than nano-tile grout usage (Pearson $\chi^2 = 33.26$). The findings indicated that there is 11.1% difference of knowledge gap on inhaling ENPs from tile grout as well as 11.2% difference for paint that contains nano TiO₂ particles. Results indicated that there is a low level of knowledge about health risks from ENPs among construction workers who ever use and never use tile grout and paint containing ENPs, while the level of exposure to both products is as high as 71.5% and 75.5%, respectively. Interestingly, proper protective equipment like filtered masks, which are recommended for ultrafine particle exposure (Registration, Evaluation, Authorisation and Restriction of Chemicals, 2008), are not commonly used in all construction site surveyed. This finding is in accordance with the HBM which indicates that low knowledge about danger leads to low measures of prevention.

Figure 2: Relationship between knowledge of health risks from inhaling ENPs and risk of exposure to TiO₂ that are contained in tile grout and paint



Pearson $\chi^2 = 18.47$, $df = 1$, $p < .001$

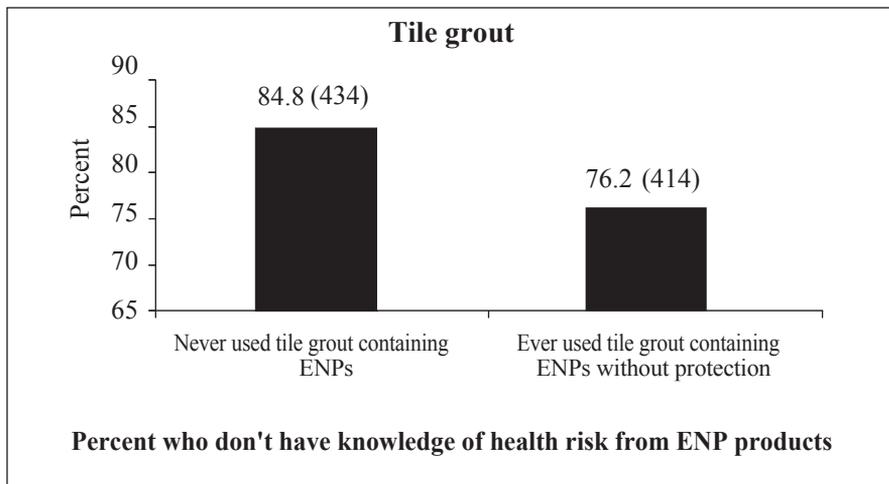


Pearson $\chi^2 = 33.26$, $df = 1$, $p < .001$

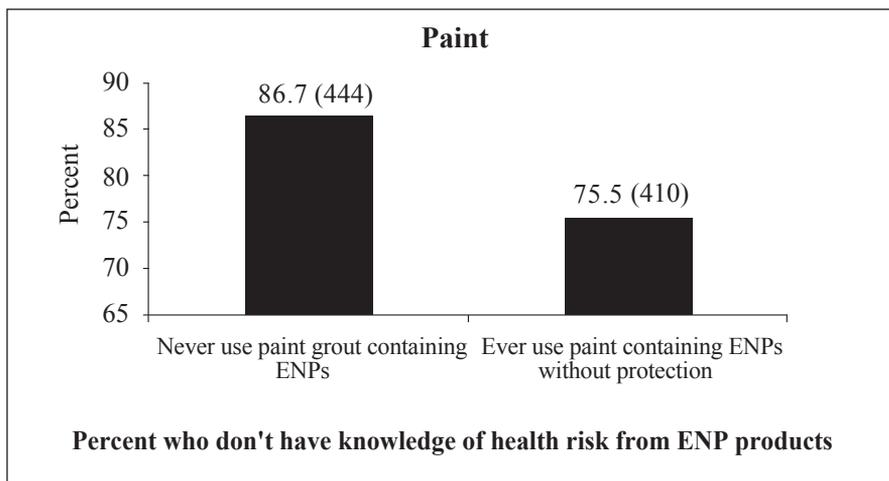
Knowledge and risk of exposure on nano TiO₂ and nano silver through skin

When focusing on possible knowledge of the potential risk of ENPs penetrating through the skin as shown in Figure 3, the pattern is similar to knowledge of inhaling ENPs in the previous figure. For example, only a small difference in knowledge exists between the health risks of ENPs through dermis between workers who use and do not use tile grouts which contain TiO₂ (8.6% difference). A similar result can be found when considering paint products containing nano silver (11.2% difference). The relationship between ever use nano-paint and having health risk knowledge is also a little higher than nano-tile grout usage (Pearson $\chi^2 = 20.65$). Most workers do not know that ENPs contained in the construction products can penetrate through dermis. Moreover, the finding reveals that low knowledge level is related to high usage of tile grout and paint at 76.2% and 75.5%, respectively.

Figure 3: Relationship between knowledge of health risks from ENP skin penetration and risk of exposure to TiO₂ contained in tile grout and paint



Pearson $\chi^2 = 12.14$, $df = 1$, $p < .001$



Pearson $\chi^2 = 20.65$, $df = 1$, $p < .001$

Determinants on knowledge of health risks from ENPs in tile grout and paint

This study also examined the probability of having knowledge and risk of exposure to ENPs by considering worker demographic and social characteristics through binary logistic regression. This allows a focus on both specific dependent outputs such as knowledge of health risks and risk of exposure to ENPs in tile grout and paint. The first of the 3 multivariate models focuses on knowledge of health risks about construction nanotech products by controlling all

demographic and social characteristic of samples such as age, education and experience in construction work. The second model focuses on the variation of work position in terms of hierarchical level to see whether there is a pre-existing knowledge difference related to job classification. The third model focuses on the variations in knowledge of health risks from ENPs related to differences in the size of firms.

Table 1: Results of logistic regression focusing on determinants of knowledge of health risks posed by nanotech products among construction workers

Characteristics	Model 1		Model 2		Model 3	
	Odd	S.E.	Odd	S.E.	Odd	S.E.
<i>Age 30-39 (ref.)</i>						
Age 15-29	1.19	0.26	1.21	0.27	1.22	0.27
Age 40+	0.54***	0.14	0.54**	0.14	0.57**	0.14
<i>Female (ref.)</i>						
Male	1.46	0.39	1.42	0.38	1.42	0.38
<i>Bachelor level (ref.)</i>						
Less than certificate	0.51**	0.10	0.89	0.26	0.89	0.26
Certificate	0.73	0.14	1.19	0.34	1.18	0.34
Diploma	0.91	0.18	1.17	0.31	1.18	0.31
<i>More than 15 years (ref.)</i>						
experience 0-5 years	1.01	0.27	1.04	0.28	1.03	0.28
experience 6-10 years	1.06	0.24	1.07	0.25	1.06	0.25
experience 11-15 years	1.27	0.30	1.25	0.30	1.24	0.29
<i>Architect/Engineer (ref.)</i>						
Construction laborers			0.42*	0.18	0.41*	0.17
Craftsmen			0.53*	0.16	0.53*	0.16
Foremen			0.87	0.26	0.86	0.26
Manager			1.03	0.31	1.03	0.31
<i>More than 49 workers (ref.)</i>						
10-19 workers					1.00	0.19
20-49 workers					1.19	0.21
Log-likelihood	-634.81		-628.31		-624.80	
df	9		13		15	
P value	0.000		0.000		0.000	
N	1,055		1,055		1,055	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Results in Table 1 focus on the influence of individual demographic factors (age, gender, educational background and work experience) on knowledge of health risk among the sample workers. Workers aged over 40, compared with those aged 30-39, are 46% less likely to be aware of the health risks posed by ENPs contained in tile grout and paint. The difference is of a statistically significant ($p < 0.001$). In a similar study, Antel and Pingali (1994) found a slightly negative relationship between age and knowledge of the risks of pesticide usage among farmers. In other study, however, it was found that older people had more knowledge about the health risks related to known dangers such as alcohol consumption and pesticide use when compared with younger people (Hermand, Mullet and Rompteaux, 1999).

As for educational levels, workers who have completed less than certificate level of education are 49% less likely to have knowledge of the health risks from ENPs contained in tile grout and paint when compared with those who have completed a bachelor's degree ($p < 0.01$). This means that better educated workers also have higher knowledge about the health risk from ENPs contained in construction products like tile grout and paint. This finding is similar to the study of Hermand, Mullet and Rompteaux (1999) about the knowledge, attitude and behaviour regarding risk perception which showed that younger and better educated people had a higher awareness of risks than less well-educated older workers. Similarly, a study of Hsairi and colleagues (1992) showed that knowledge of health risks from asbestos increased with years of education. This study also finds that a higher level of worker education is associated with the possession of more information on health risks. It may be that education allows people to develop the ability to adopt and process information more effectively, or to become more sensitive to both the benefits and potential risks of new materials.

In model 2, work position was added into the model to see whether there is any variation in effect of knowledge of health risk at individual level. It was found that low skill labours like construction laborers and craftsmen have less knowledge on health risk of ENPs when compared with architect/engineer at 58% and 47%, respectively. The difference is statistically significant ($p < 0.01$).

In model 3, size of a firm is included to examine the relationship between social influence and individual's perception about the health risks of ENPs. To elaborate, workers normally gain knowledge about new chemical usage from other experienced persons, not only through education or formal training systems, but also through their colleagues. This is called observational learning or organisational culture (Bandura, Ross and Ross, 1961; Brown, 1995). In this study, no relationship between knowledge of health risks from ENPs and firm size was found as shown in model 3. This finding may indicate that information about risk perspective of ENPs may appear at the individual rather than at the organisation level. For example, workers may learn about new products from colleagues rather than from their organizational training. Although no relationship was found between knowledge and type of organisation, it has been demonstrated that blue collar workers (craftsmen and labourers) are less likely to know about the health risks of ENPs than their white collar counterparts (architects and engineers). It is generally accepted that education and work position are related, as highly educated workers generally hold higher positions of responsibility, and these factors also have a positive relationship to the level of knowledge about the health risks of ENPs in this study.

Determinants of risk of exposure to ENPs after controlling knowledge of health impacts

Protective equipment for ENPs such as the full mask with high efficiency particulate air filter, and non-woven polyethylene shirt and gloves is not yet in common use among construction workers. This means workers who use products containing ENPs are at risk of exposure to significant health hazards (National Institute for Occupational Safety and Health, 2007). Focusing on the influence of individual demographic factors (age, gender, educational background and work experience) as indicated in model 4 of Table 3, workers aged more than 40 are 39% less likely to be exposed to ENPs contained in tile grout and paint than young workers (aged 30-39 years). The difference is statistically significant ($p < 0.05$). For education, it is found that workers who have completed less than certificate level are 49% less likely to have risk of exposure to ENPs contained in tile grout and paint when compared with those who have completed a bachelor's degree ($p < 0.05$). This finding is similar to the results of the study by Taylor and Cherrie (1998) which found no relationship between education and risk perception among workers dealing with asbestos. It may be that there are more factors influencing individual behaviour than formal education (McKenna, 1988).

However, this study found some significant effect of other factors. Workers who have less than 5 years work experience are 70% less likely to be exposed to ENPs from tile grout and paint when compared with those who have more than 15 years experience ($p < 0.001$). Also, workers who have between 11 and 15 years work experience are 52% less likely to be exposed to ENPs contained in tile grout and paint when compared with those who have more than 15 years experience ($p < 0.01$).

Considering work position and size of firm as shown in Table 2, the results showed that blue collar workers (foremen, craftsmen and labourers) are less likely to have a risk of exposure to ENPs in tile grout and paint when compared with white collar workers (architects and engineers). This is a surprising result. It was the expectation of this researcher that workers who had low knowledge about the toxic effects of ENPs would have had higher risk of exposure to ENPs than those who were better informed. This result contrasts with the the Health Belief Model (HBM) which mentions that low perceived susceptibility (low knowledge of risk) brings about low perceived barriers (low risk protection) and a consequently higher level of exposure to risk. However, McKenna (1988), and Taylor and Cherrie (1998), have revealed that other influencing factors such as organisational culture, self-belief, non experience of the health risks of chemical substances, etc. are more influential than education, and which can finally lead to ignorance on self-protection.

Table 2: Results of logistic regression focusing on determinants of risk of exposure to ENPs from construction nanotech products among construction workers

Characteristics	Model 1		Model 2		Model 3		Model 4	
	Odds	S.E.	Odds	S.E.	Odds	S.E.	Odds	S.E.
<i>Age 30-39 (ref.)</i>								
Age 15-29	1.13	0.26	1.04	0.24	1.05	0.25	1.03	0.25
Age 40+	0.64*	0.14	0.67*	0.15	0.51**	0.13	0.61*	0.14
<i>Female (ref.)</i>								
Male	1.13	0.28	1.26	0.33	1.11	0.30	1.04	0.29
<i>Bachelor (ref.)</i>								
Less than Certificate	0.32***	0.06	0.59	0.17	0.53*	0.15	0.51*	0.15
Certificate	0.41***	0.09	0.81	0.23	0.82	0.23	0.76	0.22
Diploma	0.70	0.16	1.30	0.36	1.31	0.37	1.25	0.36
<i>More than 15 years (ref.)</i>								
experience 0-5 years	0.34***	0.09	0.37***	0.10	0.32***	0.09	0.30***	0.08
experience 6-10 years	0.93	0.21	1.01	0.23	0.87	0.20	0.87	0.21
experience 11-15 years	0.52**	0.12	0.53**	0.13	0.51**	0.12	0.48**	0.12
<i>Architect / Engineer (ref.)</i>								
Construction labourer			0.36*	0.15	0.36*	0.15	0.40*	0.17
Craftsmen			0.29***	0.10	0.28***	0.10	0.30**	0.10
Foremen			0.29***	0.10	0.29***	0.10	0.27***	0.10
Manager			0.71	0.28	0.64	0.25	0.60	0.25
<i>More than 49 workers (ref.)</i>								
10-19 workers					2.94***	0.61	3.01***	0.64
20-49 workers					0.93	0.17	0.88	0.16
<i>Don't have knowledge of health risk from ENPs (ref.)</i>								
Have knowledge of health risk from ENPs							3.32***	0.63
Log-likelihood	-622.13		-612.87		-600.20		-571.87	
Df	9		13		15		16	
P value	0.000		0.000		0.000		0.000	
N	1,055		1,055		1,055		1,055	

* $p < 0.05$, ** $p < 0.01$, * $p < 0.001$

Workers who had knowledge of the health risks of ENPs were 3.32 times more likely to have risk of exposure to ENPs from construction nanotech products when compared with those who did not have such knowledge ($p < 0.001$). This result is not in accordance with the expectations because it would be reasonable to believe that people would avoid taking health related risks should they be made aware of them. However, workers who have better knowledge of health

risks may have higher exposure to ENPs due to their positive beliefs as well as social influences from their colleagues, as noted in a US study about positive views among the public towards nanotechnology (Cobb and Macoubries, 2004; Seigrist et al., 2007). The Health Belief Model (Janz and Becker, 1984) mentioned that where positive perceived susceptibility (knowledge of risk) about the toxicity of ENPs is low, action to reduce risk of ENPs would also be low. This study found the contrary; the more knowledge of risk the workers had, the more exposure they had to ENPs. The Theory of Plan Behavior (Ajzen, 1991) mentioned that subjective norms (influence of surroundings on individual attitude towards action) such as the size of the firm has some influence on worker exposure to ENPs as workers in small firm (10-19 persons) were 2.01 times more likely than workers in large firms (> 49 persons) to be exposed to ENPs contained in tile grout and paint ($p < 0.001$). This may be because workers who operate in small firms may use nanoproducts without proper knowledge about their potential toxic effects.

Conclusion

The results of this study show that the majority of the construction workforce is unaware of the health risks posed by ENPs contained in products widely used in the industry (> 70%). Interestingly, the probability of having risk exposure to ENPs is higher for those who have knowledge of the health impacts from ENPs than for those who do not. This finding highlights that even though they know they are facing some risk, other factors may influence their decision to use these new chemicals. According to the Health Belief Model, when perceived susceptibility of the individual is low (knowledge about risk), there will be low perceived barriers (limitation on risk of exposure). Also, the Theory of Plan Behavior states that normative belief and subjective norm (define as “size of firm” in this study) does not affect individual perception (knowledge about risk), but does affect individual behaviour (exposure), as smaller firms have higher exposure to products containing ENPs than large firms. The results of this study also reveal another side to this problem in terms of the connection between knowledge and behaviour among workers: that giving the workers knowledge of risk may not be sufficient to enable them to avoid those risks. Empirical evidence during the field survey showed that most construction workers, especially unskilled workers, who work closely with these materials do not use any necessary protective equipment such as filtered masks and rubber gloves due to the uncomfortably high temperatures on site. For further practice, the precautionary principle (safety first) has also been suggested by many scholars as it may help to mitigate possible health problems from using hazardous ENPs in workplaces where there is the potential for exposure until the knowledge gaps on nanotoxicity are bridged (Grunwald, 2008).

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