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RESEARCH PAPER

Awareness on adverse effects of nanotechnology increases negative perception among public: survey study from Singapore

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Abstract As has been demonstrated by recent societal controversies associated with the introduction of novel technologies, societal acceptance of a technology and its applications is shaped by consumers' perceived risks and benefits. The research reported here investigates public perceptions of nanotechnology in Singapore, where technological innovation is an established part of the economy, and it might be expected that consumer perceptions of risk are low, and those of benefit are high. The contribution of socio-demographic variables, knowledge level and exposure to risk information in shaping risk perception about nanotechnology applications within different application sectors were analysed. About ~80 % of respondents have some understanding of nanotechnology, 60 % report having heard some negative information, and 39 % perceive nanotechnology as beneficial, while 27.5 % perceive it as risky. Nanotechnology application in food was reported to cause the most concern in the consumers included in the sample. Two-step cluster analysis of the data enabled grouping of respondents into those who expressed 'less concern' or 'more concern' based on their average scores for concern levels expressed with applications of nanotechnology in different sectors. Profiling of these clusters revealed that, apart from various socio-demographic factors, exposure to risk-related information, rather than awareness in nanotechnology itself, resulted in respondents expressing greater concern about nanotechnology applications. The results provide evidence upon which regulatory agencies and industries can base policies regarding informed risk–benefit communication and management associated with the introduction of commercial applications of nanotechnology.

Keywords Nanotechnology · Consumer attitudes · Risk–benefit perception · Societal implications · Singapore

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Introduction

The potential of nanotechnology to contribute to solving problems associated with urgent societal challenges, such as the need to provide clean energy, clean water, clean air and healthcare has been well recognized (Mangematin and Walsh 2012). At present, there is a rapid expansion in the list of consumer products which utilise nanomaterials. In the case of the food sector, for example, nanotechnology applications range from products which have traditionally incorporated nanoparticles, such as titanium dioxide (TiO_2) and silicon dioxide (SiO_2) as colourants and/or anticaking agents, to more recent application of minerals in nanoform to improve their bioavailability, and nanomaterial functionalized food contact materials with improved antimicrobial and sensor properties (Duncan 2011; Chaudhry et al. 2008). In addition, nanotechnology has been extensively incorporated into consumer products such as textiles, cosmetics, sports items, sanitizers, and personal care products. This influx of nano-enabled consumer products is fuelled by market pressure, at the same time, to some extent, as being associated with lack of regulatory oversight (Coles and Frewer 2013).

To date, there has been no epidemiological study on the negative human health impacts associated with exposure to engineered nanomaterials, although laboratory-based studies have demonstrated the potential of engineered nanomaterials to cause harm to human and environment (Maynard et al. 2006). Despite this, the safety of nanomaterials to human and environmental health has been a subject of discussions in academia (Maynard et al. 2006) and in the media more generally (Friends of the Earth 2006; Toh 2011; Ho 2011; Peter D. Hart Research Associates 2007). Concerns over the safety of nanomaterials have been the impetus for advocating application of the 'precautionary principle' for the application of nanotechnologies (Nanoaction 2007; Marchant and Abbott 2013). Inevitably, the long-term market success of nano-enabled products will depend on societal acceptance of the technology and its applications (Gupta et al. 2013; Currall 2009; Satterfield et al. 2009). Societal acceptance of emerging technologies is shaped by many factors, including individual differences in acceptance or rejection of products linked to socio-demographic factors, people's level of knowledge about technology in general, and people's perceptions associated with the risks and benefits of the technology and its applications, inter alia (Gupta et al. 2012). Whilst there is evidence to suggest that nanotechnology is positively perceived by the public (Kahan et al. 2009; Siegrist et al. 2007; Harrison Interactive 2012), the provision of balanced risk–benefit information may differentially influence the attitudes held by individuals (Fischer et al. 2013).

Research addressing the attitudes of the public has frequently considered nanotechnology generically, without differentiating perceptions and attitudes focused on specific applications or application sectors (Pidgeon et al. 2009). As more and more products are becoming commercially available, one might predict more contextualised and differentiated attitudes to be observed across application domains, as it has been the case for other areas of scientific endeavours (Frewer et al. 2011; 2013). Thus, it is necessary to consider attitudes towards different types of application at the current translational growth stage as acceptability of nanotechnology may vary across different application domains. Currently, however, the results of research focused on Asia–Pacific consumer responses to different areas of application of nanotechnology are limited (Frewer et al. 2014).

A recent study has estimated that Asia will dominate the global use and release of nanomaterials to environment because of the size of the population (52 %) and rising Inequality-adjusted Human Development Index (IHDI) values (Keller and Lazareva 2013). In the Southeast Asia region, Singapore is an example of an economy that is fuelled by technological innovation, including that associated with nanotechnology and its applications (Gupta et al. 2013). However, there is a lack of information regarding the attributes of people with different levels of risk and benefit perceptions associated with nanotechnology (Pidgeon et al. 2009). Consideration of public concerns and priorities is necessary for regulatory agencies and industries to create informed and societally inclusive risk assessment and risk management frameworks and to communicate about risk governance activities with the broader community.

In a previous study, research focused on understanding experts' opinions about the drivers of societal acceptance of nanotechnology was reported. Expert respondents from North America, Europe, India, Singapore and Australia were included as study

respondents, to ensure that data were collated from experts working in different regions of the world associated with different regulatory regimes (Gupta et al. 2013). The results suggested that the experts included in the study were particularly concerned about consumer acceptance of the products of nanotechnology applied in the agri-food sector, and that acceptance of specific applications would be driven by perceived risk and consumer concerns regarding the contact with nanomaterials. However, applying a similar methodology to identify the concerns held by lay people living in the UK indicated that concerns did not align with those held by experts. Study respondents did not report particular concerns to be associated with agri-food-related applications, contrary to what had been predicted by experts. Rather ethical concerns emerged as an important factor influencing respondent acceptability or rejection of nanotechnology applications, which had not been identified as an issue by experts (Gupta 2013).

The difference in judgement could lead to societally unacceptable risk management activities on one hand and the failure to commercialise nanotechnology products on the other. However, acceptance of nanotechnology application may also vary in different cultural contexts and across different consumer segments, which was the impetus for conducting the research reported here. The overall objective was to explore consumer attitudes and perceptions in the (to date unexplored) Singaporean population. The specific aims of the research were to (1) understand the level of public awareness about nanotechnology in general and the presence of nanomaterials in consumer products specifically, (2) to understand if the different application domains of nanotechnology will lead to differential public perceptions of human and environmental health risks and (3) to understand the influence of socio-demographic attributes and the effects of risk information about nanotechnology on risk and benefit perceptions held by consumers.

Method

Singapore is a cosmopolitan city state, where the population represents a microcosm of the major ethnic groups in the Southeast Asia region (Chinese 74.2 %, Malay 13.3 %, Indian 9.2 % and others 3.3 %) (Singapore Statistics 2014). This allowed comparison of the attitudes and perceptions of people from the major ethnic groups in the region. The average literacy rate is 96.5 % where 68.8 % of the population have a secondary or higher education qualification (Singapore Statistics 2014). Unemployment is low at 2.1 % across the population of $\sim$5.4 million people (Singapore Statistics 2014). The comparatively high literacy ratio and employment rate in Singapore when compared to neighbouring nations is expected to reduce the chance of risk perceptions about newer technologies, as a consequence of reduced socio-economic vulnerability of individuals in the population (Freudenburg 1993).

Respondents and data collection

The survey was conducted among 1,080 individuals older than 15 years, from different parts of Singapore during a period from December 2012 to June 2012. Data were collected using survey methodology. The survey was developed in English (one of the official languages in Singapore that is spoken by the majority of the people). The researcher interpreted the questions for those who needed assistance with language. The final sample selected for analysis (based on complete response to the entire survey) consisted of 853 respondents where the response rate was 0.826 (calculated according to AAPOR Survey Response Rate calculation methodology). Socio-demographic characteristics of the respondents are summarized in Table 1.

Measures and data analysis

The questions were framed to gauge the public's understanding and perception about nanotechnology applications in different sectors. Most of the questions asked were congruent with similar studies conducted elsewhere with the intension to compare outcomes across studies (Cobb and Macoubrie 2004; Peter D. Hart Research Associates 2007). In addition, questions designed to assess respondent's exposure to risk-related information were also included, as the topic of health hazards of nanomaterials were actively discussed in public media (Ho 2011; Toh 2011). The original survey questions with scales and anchors are provided as supplementary information.

Table 1 Socio-demographic characteristics of the sample

Socio-demographic characteristics	%
Gender	
Male	56.9
Female	43.1
Age	
Under 18	2.9
18–36	52.3
35–47	29.9
48–66	14.7
Over 66	0.2
Ethnicity	
Chinese	38.2
Malay	22.3
Indians	32.3
Others (Caucasians, Japanese, and Filipino)	7.2
Occupation	
Student	40.2
PMET	26.0
Sales/Business	12.3
Unemployed	9.0
Housewife	7.0
Others	5.3
Educational level	
University	47.1
Polytechnic	24.2
Post-secondary	10.0
Secondary	10.4
Primary	5.0
No formal education	3.2
Nationality	
Singaporean	71.6
Permanent residents	10.0
Foreigners	18.4

First, respondents indicated their level of understanding about nanotechnology, which was used to assess their familiarity with the topic. Those who chose the option of knowing "*nothing at all*" about nanotechnology were asked to read an introductory paragraph about nanotechnology and nanomaterials, which was based on information available in the literature (Mansoori and Soelaiman 2005). Subsequently, two questions were asked about respondents' awareness about the presence of nanomaterials in consumer products and their exposure to risk-related information about nanotechnology. Another two questions focused on understanding respondents' concerns associated with human and environmental health impacts of nanomaterial. For these questions, respondents were asked to indicate their level of concern using a 5-point Likert scale (1 = being no concern, and 5 = being most concern). The different areas of application covered by the survey included nanotechnology applications in food, medicine, cosmetics and other skin products, clothing/textiles, baby products, water purification filters and electronic items. The application "scenarios" presented to assess concerns associated with contamination of drinking water and environmental health hazards were (a) silver nanoparticles used in odourless clothing, washing machines, fridges, antiseptics etc., (b) titanium dioxide and zinc oxide used in cosmetics and sunscreen products, (c) carbon nanotubes used in tyre and other automobile parts, (d) incidental or accidental release of nanomaterials from industrial production units and (e) direct application of nanomaterials for environmental remediation. Finally, two items asked about respondents risk and benefit perceptions associated with nanotechnology and the study respondents' perceived need to conduct risk assessment of nanomaterials and products containing nanomaterials.

A two-step cluster analysis was performed (SPSS 19) to obtain segments based on public understanding of risks and benefits of nanotechnology. The procedure combines sequential and hierarchical approaches by first pre-clustering and then sub-clustering the data. Log-likelihood measure was used as a distance measure. The number of clusters was determined using Bayesian information criterion. The segments were profiled with t-tests and cross tabulations (with Pearson χ^2 statistics to test significant differences).

Results

Public awareness about nanotechnology and its market penetration

Over 80 % of survey respondents reported being familiar with nanotechnology. Among the respondents, 6.9 % indicated their understanding as 'a lot', 40.3 % as 'some', 34.2 % as 'a little,' and 18.5 % as 'nothing at all'. Table 2 presents significant associations between the level of respondent understanding

Table 2 Socio-demographic differences in mean ratings and standard deviations (in parenthesis) of level of understanding on nanotechnology (1 = nothing at all, 2 = a little, 3 = some, and 4 = a lot)

Category of respondents	Mean score on the understanding of nanotechnology (±standard deviations)	*t* statistic	*p* value
Age		−9.82	0.000
47 and below ($N = 726$)	2.48 (±0.80)		
48 and above ($N = 127$)	1.67 (±0.86)		
Occupation		13.47	0.000
Students, PMET's, Sales/Business ($N = 670$)	2.55 (±0.77)		
Unemployed, housewives, and others ($N = 182$)	1.65 (±0.80)		
Educational qualification		15.03	0.000
University and Polytechnic ($N = 608$)	2.61 (±0.75)		
Post-secondary and below ($N = 244$)	1.72 (±0.79)		

associated with nanotechnology, and socio-demographic variables, in particular, age, occupation and educational level. The level of understanding of nanotechnology was higher for respondents aged 18–47 (in comparison to older respondents, who are 48 and above) ($t = 9.82$, $p = 0.000$). Further, the level of understanding was higher among students, Professionals, Managers, Executives and Technicians (PMET's) and individuals working in sales/business in comparison with participants who reported their occupational status as unemployed, housewife and others ($t = 13.47$, $p = 0.000$). Polytechnic and university graduates also reported greater familiarity with nanotechnology in comparison to those having post-secondary and below educational qualifications ($t = 15.03$, $p = 0.000$). There was no significant effect associated with ethnic group or gender ($p < 0.001$) in this regard. Overall, the results suggested that understanding about, and familiarity with, nanotechnology is higher among younger and educated respondents, and among students and those with relatively high-income jobs.

The results also indicated that about half of the respondents (48.2 %) were, to some extent, aware of the availability of consumer products containing nanomaterials. Table 3 shows statistically significant associations between reported awareness about consumer products containing nanomaterials and socio-demographic variables. Compared to females, male respondents reported being aware of consumer products containing nanomaterials frequently ($\chi^2 = 12.02$, $p = 0.001$). Younger respondents (47 and below) were more aware of consumer products containing nanomaterials in comparison to those who were 48 and over ($\chi^2 = 13.75$, $p = 0.000$). Similarly, respondents who reported their occupation as students, PMET's and as working in sales/business reported more awareness of product availability than those who identified themselves as unemployed, housewives or "others" ($\chi^2 = 56.43$, $p = 0.000$). Respondents with university and polytechnic degrees also reported more awareness than those with post-secondary and below qualifications ($\chi^2 = 46.27$, $p = 0.000$). Overall, the results suggested that awareness regarding nanotechnology being used in consumer products is higher for male, young and educated respondents, and for those with relatively high-income jobs.

Risks versus benefits perception

Risk and benefit perceptions were scored for nanotechnologies in general and specifically within different application domains. In the case of nanotechnologies in general, 39.5 % of the respondents perceived benefits of nanotechnology to outweigh potential risks, 27.5 % perceived risk being higher

Table 3 Socio-demographic differences in mean ratings and standard deviations (in parenthesis) of awareness of consumer products containing nanomaterials (1 = most of the times, 2 = sometimes, 3 = not sure, and 4 = not at all, 1 and 2, and 3 and 4 were combined for the analysis)

Socio-demographic factors	χ^2 statistic	*p* value
Gender	12.02	0.001
Age	13.75	0.000
Occupation	56.43	0.000
Educational qualification	46.27	0.000

than benefits, 20.9 % perceived risk and benefits to be equal and 12.1 % were 'unsure'. A higher proportion of respondents with some level of understanding of nanotechnology (a lot, some, or a little) perceived that the potential benefits of nanotechnology outweighed the risks. In particular, 43.2 % of respondents with some level of understanding about nanotechnology reported perceiving benefits to outweigh the risks, 30.6 % reported perceiving risks outweighing benefits, 19.2 % perceived benefits and risks as equal and 7.6 % were "not sure" about the benefits and risk ratio. A higher proportion of respondents with no understanding about nanotechnology indicated that they were not sure if benefits outweighed the risks or vice versa. Among respondents with 'no understanding about nanotechnology', 28.5 % indicated that they perceived the benefits and risks to be equal, and 34.17 % reported that they were not sure.

The subsequent analysis focused on understanding the public's level of concern associated with nanotechnology applied in different domains (Table 4). The results demonstrated that respondents were mostly concerned about nanotechnology/nanomaterial applications in food, while being least concerned about the applications in electronic items. The mean values for "ecological" concerns ("possible contamination of water" and "ecological threat posed by use and/or dumping of nanomaterials") are presented in Table 4. The results indicated that respondents are mostly concerned about direct application of nanomaterials in the context of environmental remediation, and incidental or accidental release of nanomaterials from industrial production units. The data focused on concerns about human health and ecological threats posed by nanomaterials/nanotechnology were further subjected to cluster profiling to identity factors that influence respondents' attitudes towards nanotechnology.

Table 4 Mean values and standard deviations for the concern about nanotechnology/nanomaterials in different application sectors in relation to human health and ecological threat

	Mean score for the concern levels (±standard deviations)
Domain of nanotechnology applications	
Food	4.20 (±1.04)
Medicine	3.96 (±1.18)
Baby products	3.86 (±1.06)
Water purification filters	3.63 (±1.08)
Cosmetics and other skin products	3.19 (±1.20)
Clothing/textile	3.11 (±1.25)
Electronic items	2.85 (±1.46)
Possible scenarios of environmental contamination by nanomaterials	
Direct application of nanomaterials for environmental remediation	3.37 (±1.12)
Incidental or accidental release of nanomaterials from industrial production units	3.35 (±1.04)
Silver nanoparticles used in odourless clothing, washing machines, fridges, antiseptics etc.	3.25 (±1.15)
Titanium dioxide and zinc oxide used in cosmetics and sunscreen products	3.16 (±1.02)
Carbon nanotubes used in tyre and other automobile parts	3.03 (±1.06)

1 being no concern, *5* being most concern

Cluster profiling for identifying factors that shape attitudes

A two-step cluster analysis was conducted where respondents were optimally clustered into two clusters (SPSS 19.0). A two-cluster solution appeared interpretable, consisting of 46 and 54 % of the respondents in the sample. Table 5 shows the mean values of the concern items within the two clusters and the ''ranking'' (values given in brackets) within the clusters. The *F* statistics value provided in Table 5 indicates the magnitude of difference between clusters for each concern items. Applications of nanotechnology/nanomaterials in medicine, food, baby products and water purification filters in that order were the most concerning items among respondents from both clusters. The results indicated that concern levels reported by respondents in cluster 1 were lower than that reported by respondents in cluster 2. Therefore, cluster 1 is labelled as comprising ''less concerned" respondents and Cluster 2 as "more concerned" respondents. Further, the profiles of these two clusters of respondents with regard to their level of understanding about nanotechnology, their awareness about the presence of nanomaterials in consumer products, their exposure to risk-related information,

Table 5 Cluster analysis data showing differences in mean values for the concern items among the two clusters

	Cluster 1 (46 % of sample)	Cluster 2 (54 % of sample)	*F* statistic	*p* value
Domain of nanotechnology applications				
Food	3.48 (2)	4.81(2)	341.34	0.000
Medicine (therapeutic nanomaterials administered)	3.13 (1)	4.67 (1)	99.78	0.000
Cosmetics and other skin products	2.68 (8)	3.62 (8)	12.68	0.000
Clothing/textile	2.58 (9)	3.55 (9)	11.05	0.001
Baby products	3.17 (3)	4.46 (3)	27.47	0.000
Water purification filters	2.94 (4)	4.21 (4)	1.21	0.272
Electronic items	2.27 (10)	3.35 (10)	35.90	0.000
Possible scenarios of environmental contamination by nanomaterials				
Silver nanoparticles used in odourless clothing, washing machines, fridges, antiseptics etc.	2.88 (12)	3.57 (12)	12.12	0.001
Titanium dioxide and zinc oxide used in cosmetics and sunscreen products	2.73 (7)	3.54 (7)	28.57	0.000
Carbon nanotubes used in tyre and other automobile parts	2.64 (11)	3.37 (11)	6.95	0.009
Incidental or accidental release of nanomaterials from industrial production units	2.89 (6)	3.73 (6)	17.81	0.000
Direct application of nanomaterials for environmental remediation	2.85 (5)	3.81 (5)	4.06	0.044

1 being no concern, *5* being most concern

their opinion about the need for conducting safety/risk assessments and their perceived risks versus benefits regarding nanotechnology/nanomaterials were assessed to understand which factors influenced their attitude. The results are provided in Table 6. Differences in mean concern levels expressed about nanotechnology/nanomaterial applications across the segments are reflected in significant differences in "having heard about any *bad effect* of nanotechnology/nanomaterial," and "opinion on the need for conducting safety/risk assessments of nanomaterials and products containing nanomaterials." The more concerned respondents reported more frequently having heard about the bad effects of nanotechnology/nanomaterial ($t = -3.286$, $p = 0.001$). Similarly, these respondents reported that they were more in favour of conducting safety/risk assessments of nanomaterials and products containing nanomaterials ($t = -3.845$, $p = 0.000$). Notably, no significant difference was found between the two clusters regarding the respondents' level of understanding about nanotechnology ($t = -0.544$, $p = 0.587$).

Differences between the cluster means in awareness about products containing nanomaterials, opinion on risks versus benefits of nanotechnology, and socio-demographic variables are presented in Table 7. Interestingly, 'less concerned' respondents reported being 'not sure' about the presence of nanomaterials in consumer products and 'more concerned' respondents reported the converse ($\chi^2 = 16.529$, $p = 0.001$). In addition, respondents reporting more concern respondents mostly think that the risks of nanotechnology outweigh the benefits, or that benefits and risks are equal ($\chi^2 = 9.870$, $p = 0.002$).

Significant differences regarding reported concern levels between socio-demographic variables were identified, with the exception of gender ($\chi^2 = 0.974$, $p = 0.324$). The more concerned respondents were more likely to include respondents over 48 or under 36 ($\chi^2 = 22.551$, $p = 0.000$). Malaysian and Indian respondents tended to belong to the 'more concerned' group, whereas Chinese respondents and members of other ethnic groups tended to belong to the 'less concerned' group ($\chi^2 = 20.299$, $p = 0.000$). The less concerned group also contained more students, whereas the more concerned group contained more unemployed people and housewives ($\chi^2 = 11.828$, $p = 0.037$). University graduates and respondents who had only completed a secondary education or below tended to belong to 'more concerned' group, whereas

Table 6 Attributes of 'less concerned' (Cluster 1) and 'more concerned' (Cluster 2) respondents

Attributes	Cluster number	Mean	t	p value
Level of understanding on nanotechnology	1	2.34	−0.544	0.587
	2	2.37		
Having heard about any '*bad effect*' of nanotechnology/nanomaterial	1	1.85	−3.286	0.001
	2	2.07		
Need for conducting safety/risk assessments of nanomaterials and products containing nanomaterials	1	4.02	−3.845	0.000
	2	4.32		

1 being no concern, *5* being most concern

Table 7 Differences between the cluster means of 'less concerned' and 'more concerned' respondents in awareness, perceived risks versus benefits, and socio-demographic variables

Attributes	χ^2	p value
Awareness of consumer products containing nanomaterials	16.529	0.001
Opinion on the benefits versus risks of nanotechnology	9.870	0.002
Socio-demographic variables		
Gender	0.974	0.324
Age	22.551	0.000
Ethnicity	20.299	0.000
Occupation	11.828	0.037
Education	32.672	0.000
Nationality	11.914	0.003

polytechnic graduates tended to belong to the less concerned group ($\chi^2 = 32.672$, $p = 0.000$). The more concerned group contained more foreigners, whereas the less concerned group contained more permanent residents of Singapore ($\chi^2 = 11.914$, $p = 0.003$).

Discussion

Public awareness about nanotechnology and its market penetration is relatively high in Singapore

Subject familiarity has been identified as one of the factors that contribute to publics' confidence in newer technology (Priest and Greenhalgh 2012). Familiarity with nanotechnology (as measured by the 'public's understanding' about nanotechnology in the research reported here) was found to be relatively higher among respondents from Singapore when compared to subject familiarity among respondents from the US, the UK and Germany (Kahan et al. 2009; Satterfield et al. 2009; Harrison Interactive 2012; Zimmer et al. 2008). Approximately, 80 % of respondents sampled in this study reported at least some understanding about nanotechnology. The relatively higher understanding about nanotechnology might be attributed to the generally higher education levels (Statistics 2014) and exposure to science topics through public media in Singapore (Ho 2011). Previous studies have shown that awareness about nanotechnology may potentially influence peoples' perceptions regarding whether risk outweighs benefit or vice versa as well as their judgements regarding the rejection or acceptance of products developed using nanotechnology (Kahan et al. 2009). Therefore, we assessed the relationship between participants' understanding about nanotechnology and their perceptions on benefits and risks of nanotechnology.

While 39 % of respondents were of the opinion that the benefits of nanotechnology outweighed the risks, the converse was true for 27.5 % of the sample. This is in contrast to the results reported by similar studies from Germany and the USA (Harrison Interactive 2012; Zimmer et al. 2008). A meta-analysis of survey studies from the USA reported that study participants tended to be optimistic about nanotechnology, despite the low level of public awareness (Satterfield et al. 2009). They found that the low level of subject familiarity contributed to increased 'uncertainty' regarding participant judgements on risks and benefits. It was predicted that exposure to "risk centric" information could lead to negative societal perception about nanotechnology (Satterfield et al. 2009). Congruent with these observations, the relatively low percentage of 'not sure' responses on the risk–benefit relationship from our study could be a consequence of the relatively higher subject familiarity with nanotechnology.

The levels of concern reported by participants were higher for those nanotechnology/nanomaterials applications utilised in food and medicine, but lower for electronic and textiles applications. It is of interest to note that the growth pace of nanotechnology application is highest in the food-related and medical sectors.

The market segment for nano-enabled food and beverage packaging increased from US$4.13 billion in 2008 to US$7.30 billion in 2014 at a compounded annual growth rate of 11.65 % (Smolander 2010). This rapid growth of nanotechnology applications in food is taking place at a time when public sentiment is potentially negative. Industries have responded by avoiding terminology referring to 'nanotechnology' in the product composition label. Thus, the influx of nanotechnology applications in food may lead to a societal distrust in nanotechnology industries and those regulatory bodies with responsibility for developing and applying relevant regulations.

Socio-demographic differences as determinants of attitudes towards nanotechnology

One of the unique features of this study is the clustering of respondents into 'less concerned' and 'more concerned' based on the average score of their concern levels regarding nanotechnology applications within different domains. This clustering allowed identification of the socio-demographic characteristics of respondents from each category that shape their perceptions about nanotechnology.

The reported level of understanding of nanotechnology did not differentiate the two clusters. However, within the 'more concerned' cluster, there was a significantly increased proportion of people who had heard about the '*bad effects*' of nanotechnology. This suggested that respondent's risk perceptions may be shaped by the type of information reaching the public. Alternatively, this result may be a consequence of respondents selecting information which reinforces their existing attitudes. Higher levels of familiarity with nanotechnology were associated with higher benefit perceptions in general, although this effect disappeared when the application domains were contextualised; there was no direct relationship between familiarity and 'benefit' perceptions. However, the assumption that the publics' confidence and support for nanotechnology will improve as their familiarity with both the technology and its applications is challenged by our observation (Vandermoere et al. 2011). Rather, it is suggested that perceptions are "fine-tuned" by the perceived attributes of specific product attribute, a finding common to other areas of technological innovation (see also Frewer et al. 1997). Given the discussion about potential adverse effect of nanotechnology in the public media in Singapore (Ho 2011; Toh 2011) and the relatively lower proportion of ambivalent respondents, it is reasonable to argue that the polarized opinion is formed by the availability of risk-related information (see also Donk et al. 2011; Metag and Marcinkowski 2013). This study also showed that the 'less concerned' group was more likely to include respondents who reported being 'not sure' about which consumer products containing nanomaterials, while those from 'more concerned' group contained more respondents who reported that they are aware of products containing nanomaterials, as well as participants who reported lack of awareness in this regard. Thus, awareness of consumers about the presence of nanomaterials in products may increase their concerns, and increased demand for safety standards is reflected by higher scores on the item assessing perceived need to conduct risk assessment studies.

Conclusions

The Singaporean publics' perceptions and awareness of and concerns about the general and sector specific application of nanotechnology were assessed. Familiarity with nanotechnology per se does not necessarily result in more positive perceptions but could lead to either positive or negative attitudes. The results support Kahan et al.'s observation that ambiguity regarding perceived risks and benefits associated with nanotechnology is reduced as people become more familiar with it (Kahan et al. 2009). However, risk information could increase risk perceptions associated with nanotechnology. This may be particularly true in the agri-food sector. This is because concern levels associated with nanotechnology applications in food was higher for respondents included in this research. There has been little attention devoted to understanding factors that could increase publics' confidence in nanotechnology applications in food. The outcome of such studies will support industry and regulatory agencies in alignment of research and development activities in line with societal priorities.

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