



Communicating pesticide neurotoxicity research findings and risks to decision-makers and the public



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ABSTRACT

The extensive research findings on neurotoxic risks of pesticides tend to remain in academic publications rather than being comprehensibly communicated to decision-makers and the public. Protecting health and promoting risk reduction, particularly in developing countries, requires access to current findings in a format that can inform policy, regulations, behaviour change and risk reduction. Successfully communicating research findings may require multiple strategies depending on the target audience's varying comprehension skills (e.g., numeracy literacy, visual literacy) and ability to interpret scientific data. To illustrate the complexities of risk communication, a case study of exposure to neurotoxic street pesticides amongst poor, urban South African communities attempting to control poverty related pests, is presented. What remains a challenge is how to communicate neurotoxicity research findings consistently and in a meaningful manner for a lay audience, consisting of both the general public and decision makers. A further challenge is to identify who will monitor and evaluate the ways in which these findings are communicated to ensure quality is maintained. Ultimately, researchers should carry the responsibility of knowledge translation and engaging with communication specialists when appropriate. Additionally, institutions should reward this as part of promotion and academic accolade systems, and funders should fund the translational process. Ethics review boards should also play an instrumental role in ensuring that knowledge translation is part of the ethics review requirement, while professional societies should take more responsibility for disseminating research findings to non-academics.

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1. Introduction

Research findings detailing the long-term health effects of neurotoxic pesticides need to be communicated in such a manner that a lay audience, including decision-makers, pesticide users and the general public, can use this information to reduce and manage risk. Understanding health risks and the associated research findings is the crucial prerequisite to decision-making and promoting behaviour changes. For evidence-informed decision-making to be valid and appropriate risk reduction behaviours to occur, the lay audience must understand the information as accurately as possible. However, researchers seldom perform the complicated task of communicating risks and uncertainties findings to target audiences. Research findings of neurotoxicological effects associated with pesticide exposures should thus be

accessible and comprehensible to decision-makers and the public, particularly in developing countries, for multiple reasons.

Current health research paints a picture of severe risks for users and the public exposed to possible neurotoxic pesticides. Many pesticides, which control pests, fungi or weeds through disrupting cellular mechanisms or targeting nervous systems (Costa et al., 2008; Keifer and Firestone, 2007), are neurotoxic to humans (Bjørning-Poulsen et al., 2008). Exposure to neurotoxic pesticides is high in developing countries in agricultural and domestic contexts. Moreover, sensitivity to exposure is higher amongst vulnerable populations in these countries; particularly women, children (child labour continues in many developing countries), the elderly, the immune-compromised and malnourished. Examples of populations at risk include farmers, farmworkers, pest control operators, malaria control applicators and bystanders (Ngowi et al., 2013; Kegley et al., 2003; London et al., 2002; Singer, 1999). Evidence of chronic neurotoxic effects (London, 2009; Wesseling et al., 2002), including effects on the brain, particularly those of children, are a key concern (Grandjean et al., 2006; Rohlman et al., 2005; Weiss,

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2000). This situation characterized by high exposure to neurotoxins combined with vulnerable populations, requires urgent risk reduction and mitigation measures.

While research results are not always conclusive, they provide risk information relevant to the development of pesticide legislation and policy, for developing exposure reduction and control mechanisms, and for the development and implementation of interventions. Decision-makers and those tasked with implementing pesticide legislation have access to a hierarchy of control and prevention mechanisms used in occupational and environmental health for risk reduction, which should be implemented in line with research findings. These include elimination of the pesticide, substitution of the pesticide, implementing engineering and administrative controls, changing behaviours, and advocating the use of PPE (Quality Systems and Toolbox, 2013; Runyan, 2003). Hyder and colleagues (2011), in their research with policy makers from low and middle income countries, identified that decision-makers value access to research findings. This suggests that with better access to research findings policy makers are likely to respond with more relevant policies.

To reduce risks, pesticide users, both in the work and home context and the general public require health risk and potential health risk information to be communicated in a manner different than for decision-makers. The information required for this group needs to be relevant for individual behaviour changes and for the public to understand why exposure reduction behaviours are needed to prevent short- and long-term health effects. Little has been published on the impact of the public having access to research findings, unless these individuals participated in a research study. The public is not a homogenous group easily targeted through one channel. Quandt and colleagues (2004) argue that risk communication mechanisms and processes exist for communicating general risk messages, but not to transfer specific risk messages linked to specific exposure outcomes or research findings, particularly in relation to pesticides. Currently, research scientists predominately publish their results in journals or present them at subject specific conferences which limit the dissemination of their findings to decision-makers or the public. The focus of this article, therefore, is on improving communication of research findings linking neurotoxic pesticides and potential health effects for a lay audience.

This article starts by briefly looking at what is understood by risk communication, the goals of communication and its evolution. Then it examines key issues researchers need to take into account when translating research findings for decision-makers versus the general public. To illustrate these points, a case study is presented. Lastly, the article concludes with recommendations for researchers, funders, institutions and professional societies identifying how each can promote a better lay understanding of neurotoxic risks from pesticide exposures.

2. Communicating risks

2.1. Risk communication

Risk communication is generally characterized as the provision and exchange of information regarding the nature, extent, consequence, and control of a threat (Miller and Solomon, 2003; Rother, 2005). More progressive risk communication endeavours, particularly in developed countries, view this process as a two-way exchange of information between experts and a target audience. The risk communication process in developed countries has evolved through numerous stages redefining the goal each time by building on previous stages (Fischhoff, 1995). This transition has been from being seen as a means of brain washing by experts and industry, using a top-down approach to information provision, to

community engagement and participation in a two-way communication process (Morgan et al., 2002). The communication objectives, however, continue to vary depending on the agenda of the risk communicator. Some of these goals include communicating risks to promote intended safety behaviours (motivating action); building trust in the communicator, such as in government or industry; initiating a public participation process to change or influence the public's perception of a particular risk, to educate and raise awareness, and to reach agreement on an issue (Frewer, 2004; Morgan et al., 2002; Rowan, 1991). The goal of risk communication depends on both agenda and target audience. For example, informing farm workers of potential neurotoxic risks from exposure to organophosphates to increase respirator use compliance differs from informing decision-makers that chlorpyrifos requires stricter legislated controls when used in agriculture to reduce exposures and potential neurotoxic effects.

In the context of this article, risk communication is viewed as a process of information provision or knowledge transfer about risks, particularly in relation to their magnitude and reduction measures to promote informed decision-making. Ideally risk communication should be a two-way exchange of information between the lay audience and experts in order to develop common initiatives for reducing risks (Hampel, 2006). Although this is an ideal to strive for in developing countries, the initial process needs to focus on:

- (1) improving access to and provision of coherent information about risks and uncertainties, that is, fostering "right-to-know" and
- (2) providing additional means to support understanding of risk communications, that is, fostering a process to support the "right-to-comprehend" this information (Klaschka and Rother, 2013; Rother, 2011).

An important issue with risk communication is to identify whose responsibility is it to communicate potential health risks to various audiences. In this article, I argue that researchers have a responsibility to share their peer reviewed and scientifically sound research findings. They particularly have a responsibility in sharing findings that illustrate a negative effect and uncertainty of a causal effect. I further argue that institutions and professional societies play a key role in supporting the practice and training of researchers in communicating their findings, and that academic merit should be awarded for these efforts.

Although this article focuses on the type of information required when communicating potential risks and the relevant mechanisms used for communicating these, it is important to understand that the context and frame of reference within which this communication takes place impacts on the understanding, or a lack of understanding, of the information presented. Researchers are not communicating their findings into a vacuum, but instead decision-makers and the public may have preconceived perceptions such as beliefs or attitudes about pesticide neurotoxic risks influenced by various sources, including social structures, cultural beliefs, and media reports. Indeed, sometimes risk communication mechanisms are used to alter lay audiences' perceptions of a particular health or environmental risk. What needs to be taken into account is that risk perceptions influence the understanding of risk communication mechanisms (Rother, 2011), and that various theories and methodologies exist to document and understand these (Morgan et al., 2002).

3. Communicating research findings

This section examines key issues for communicating research findings that researchers need to be cognisant of and particularly

highlights the different issues in translating findings for decision-makers versus the general public.

3.1. Communication goals of research findings

Researchers are unlikely to be motivated to publicize their results to a lay audience when such a translation of research findings into a more accessible format is onerous and costly, and is not valued financially or intellectually within the academy.

Discussions, however, within the neurotoxicology and neuro-behavioral research community have encouraged researchers to broaden their roles. This is suggested by Anger's (2007) invitation to the neurobehavioral research community to expand their focus to include risk prevention activities (e.g., training) and London's research (2009), highlighting researchers' need for trans-disciplinary engagement to move beyond just training and to include, for example, communication mechanisms between researchers and a lay audience). Furthermore, within the broader research community, there are emerging trends to foster research results dissemination, but these are not coordinated nor practiced by all researchers. These fall under various gambits and use different terminology (Schillinger, 2010 presents useful Center for Disease Control – CDC – defined terminology). For example, the US National Institute for Health and the CDC have categorized the evolving fields of effectiveness research, diffusion research, and dissemination and implementation sciences to fall under the title of *translation research* (Schillinger, 2010). Under the framework of community-based participatory research (CBPR), for example, reporting back bio-monitoring results to participants is aimed at promoting prevention measures (Morello-Frosch et al., 2009; Arcury et al., 2001). CBPR is also used in the context of environmental justice and public health activities as a means for a lay audience to have access to information about their health in relation to toxic exposures (Brown et al., 2010; Brody et al., 2009). In this article, however, the focus is on pesticide researchers' sharing their findings in relation to neurotoxic research and advocates for more consistent engagement in this approach.

Through communicating research findings in a format accessible for a lay audience, researchers engage in a more active and applied exposure and health risk prevention approach – thus putting their research into action. Examples include the “Getting Research into Policy and Practice (GRiPP)” approach (Nath, 2007)

and the translating research into policy approach (Lavis et al., 2012). Through a process of translating research findings, researchers are not merely engaging in altruistic and socially responsive research, but as Fig. 1 schematizes, researchers obtain direct academic benefits as well through producing policy relevant research and receiving recognition thereof, as well as having access to research subjects through CBPR methods (Brown et al., 2012; Snipes et al., 2009; Arcury et al., 2001).

For decision-makers, involved in public health policy, occupational health policy, agricultural/pesticides policy, and environmental health policy, the goal is to prompt policy changes through implementing appropriate legislation and regulations which reduce negative effects while promoting production and trade (Fig. 1). Aply put by a South African government official, “we rely on researchers' findings to inform policy; researchers need to ensure we have access to and know about these findings” (personal comm., 2011).

Communicating risk findings to those intentionally and unintentionally exposed to pesticides and pesticide residues tends to focus on the individual rather than broader population. The goal is to alert this audience to the potential acute and chronic health effects with the expectation that this information will promote an informed population eventually resulting in individual behaviour changes that reduce exposures and risks (Fig. 1). Many national and international laws and regulations (particularly in developed countries) make provision for a “right-to-know” principle, referring to the public's access to chemical risk information, which led to legislation and regulations including systematic approaches to risk communication. This right-to-know principle is not only a legal provision of access to risk assessment data or emissions data, but is also a human right to access to a spectrum of data and findings such as the multitude of health research findings. Unfortunately, in many developing countries this legislation is non-existent or not put into practice, especially for most at risk populations.

Although the specific goals and benefits of research may differ for researchers, decision-makers and the general public (Fig. 1), there is ultimately the mutual benefit of the reduction of exposure to neurotoxic pesticides and the potential related health effects, for all three role players. Decision-makers and the public have been identified as key role players in preventing neurotoxic pesticide exposures and yet are often the least likely to understand or have

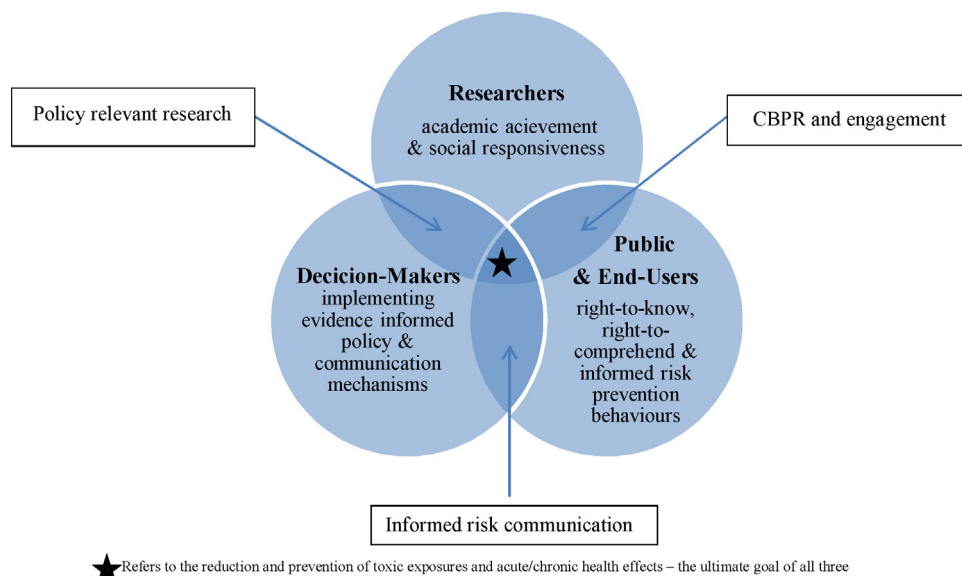


Fig. 1. Varying goals (circles) and promotion of mutual benefits from engagement (rectangles) in communicating research findings.

Table 1
Comparison of key risk communication contexts for decision-makers versus the public.

Context	Decision-makers	General public and end-users
Type of information needed	<ul style="list-style-type: none"> • Understandable/transparent statistics/evidence of risks and benefits • Uncomplicated numerical findings – easily understood • Uncertainties • Rationales for action • Population-based exposure results 	<ul style="list-style-type: none"> • Uncomplicated/non-technical findings/results in language of lay audience • Known and potential risks • Known and potential benefits • Realistic and implementable strategies for managing risks • Individual-level exposure results for study participants
Communication methods (responsible communicator)	<ul style="list-style-type: none"> • Policy briefs (researchers, NGO's) • Risk assessment data (industry, researchers) • Journal articles (researchers) • Media (researchers, NGO's) • Web based (researchers, industry, government) • Forums to discuss findings (conferences, researchers) 	<ul style="list-style-type: none"> • Print formats and media-posters, pamphlets, fact sheets, videos, radio programmes, TV (researchers, gov't, NGOs) • Pesticide labels (gov't and industry) • Face-to-face ⇒ e.g., training, educational programme, explaining findings (researchers, clinicians) • Interactive communication platforms (researchers, government, NGO's)
Risk communication formats	<ul style="list-style-type: none"> • Transparent • Uncomplicated language of technical concepts • Basic statistics (e.g., percentages, incidences, prevalence, probabilities) • Graphs, tables and figures 	<ul style="list-style-type: none"> • Non-technical, basic and transparent • Basic written language • Icons, symbols, pictograms, colour • Verbal messages
Comprehension skills required	<ul style="list-style-type: none"> • Risk literacy (e.g., numeracy skills, statistical literacy, technical/basic science literacy) • Risk/benefit analysis 	<ul style="list-style-type: none"> • Basic literacy • Basic risk literacy (e.g., numeracy, graph literacy) • Visual literacy • Health literacy (understanding of short and long term health risks)
Action expectations	<p><i>Population based</i></p> <ul style="list-style-type: none"> • Change legislation/policy • Enforce existing legislation • Implement hierarchy of control (e.g., substitution, banning, administrative, PPE use) 	<p><i>Individual behaviour based</i></p> <ul style="list-style-type: none"> • Change current behaviours • Promote safety behaviours (predominately correct PPE use) • Comprehend risks as scientifically intended

access to relevant research findings. The next section compares key risk communication contexts for each target audience to guide researchers on how to improve on understanding of findings and risk information.

3.2. Comparison of key risk communication contexts

Table 1, based on a review of the literature, highlights five key risk communication context areas for each of these role players that researchers need to address in order to improve access to and comprehension of research findings – namely the type of information required from researchers, the current methods used for communicating this information, in what format the information should be presented, what comprehension skills the target audience requires to understand the research findings/risk information, and what actions are assumed these target audiences will implement after comprehending the risk information/research findings.

3.2.1. Type of information needed

As the goals for communicating neurotoxic research findings vary so the information required from research findings varies. Table 1 highlights that decision-makers and the public require different information depending on if it is for policy and legislation or for risk reduction safety behaviours. Ultimately both require results, but the type of results (Tables 2 and 3) and the format (Table 1) varies. For example, a farm worker does not need to know whether a research finding is statistically significant or not but needs to understand the implications of the risk of short and long

term exposures and which pesticides are in their environment or bodies, as well as the exposure reduction measures available for their context. In contrast, decision-makers need to engage with and weigh up risk uncertainties based on inconclusive research findings. For example, if a pesticide has a high acute toxicity based on hazard assessments and research shows potential neurotoxic, neurobehavioural effects, then protection measures such as the precautionary principle or substitution/elimination could be implemented. On the other hand, the public need not necessarily deal with uncertainties in the data for which statistical literacy is required but rather focus on exposure reduction measures (Ben-Zvi and Garfield, 2004; Gal, 2002). To illustrate this point, Table 2 demonstrates examples of the more specific type of information that would assist decision-makers with policy and regulation development, updating of legislation, and exemplifying the need for policy implementation. Table 3, on the other hand, presents examples of information end-users of pesticides and the general public need to increase their understanding of the link with pesticides and health risks, and thus the need for risk reduction behaviours. At times the same information is required for both audiences (e.g., access to bio-monitoring data) but how the information is presented and the purpose it is used for will vary. It is important to emphasize, however, that although research findings need to be presented in a manner relevant for the target audience, these audiences should still have access to the original sources of information.

The ultimate goal of providing decision-makers with research results is to facilitate research informed policy making – that is, evidence based policy and a rationale for action (Table 2). Current

Table 2

Examples of types of information needed for decision-makers.

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- **To promote critical understanding of pesticide risk assessments**
 - a. *Understanding surveillance data from human populations*: How to interpret data on poisonings to evaluate the implication for registration such as the underestimation of burden of disease due to acute pesticide poisoning (Dawson et al., 2010)
 - b. *Interpreting toxicological data*: How to interpret data on poisonings to evaluate the implication for registration such as human toxicity data versus rat toxicity data (Prüss-Ustün et al., 2011)
 - c. *Providing information excluded from risk assessment process*: Understanding research findings on developmental neurotoxicity of inert/adjuvants/coformulants in pesticide formulations and the implications for registration and regulation which focuses on active ingredient data (Cox and Sorgan, 2006)
 - d. *Interpreting measures of effect in epidemiological studies*: How to interpret relevance of Odds Ratio and confidence intervals for policy relevance. Presenting findings in non-confusing formats (e.g., absolute versus relative risk bar graphs; Kurz-Milcke et al., 2008)
 - **For understanding the application to wider policy system for decision-making**
 - a. *Interpreting pesticide neurotoxic research findings relevance for the broader policy system for pesticide risk management* (e.g., health – Hyder et al., 2011, environment, agriculture, trade)
 - **For incorporating uncertainties into policy and regulations**
 - a. *Interpreting whether inconclusive findings have policy relevance*: The presence of performance deficits on some tests may have unclear clinical significance for individuals, but may signal a population effect – needing remedial action at a policy level
 - b. *Research findings indicating potential causal links between negative effects and pesticides*: There is mounting evidence that pesticide exposure may be an important environmental risk factor for Parkinson disease (Pezzoli and Cereda, 2013; Giasson and Lee, 2000)
 - c. *Interpreting and applying uncertainty into protective policy measures*: How to interpret risk estimates when there is uncertainty. How do decision-makers decide (for example) in what way a pesticide should be labelled?
 - **Providing rationales for action based on evidence**
 - a. *Ability to discern “effectiveness” of interventions for risk reduction*: Limiting availability of highly hazardous pesticides in Sri Lanka reduced exposure (i.e., poisonings) and access (e.g., for self-harm) (Roberts et al., 2003)
 - b. *Research findings for standard setting and understanding how to address data conflicts*: Many epidemiology studies have shown high-dose (and in some cases low-dose chronic) exposures to most pesticides results in neurotoxicity which is more appropriate for regulation than the extrapolation from animal toxicity studies. These study findings need to be integrated into policy to reduce neurotoxic effects (Alavanja et al., 2004)
 - **Results needed that are for population-based exposures**
 - a. *Ability to interpret research findings for population based regulations*: Require population/aggregate based results (e.g., through transparent graphical representation; Morello-Frosch et al., 2009; Kurz-Milcke et al., 2008) or generalizable study results. Findings need to represent most at risk populations from pesticide exposures
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Table 3

Examples of types of information needed for end-users and the general public.

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- **Uncomplicated/non-technical findings/results in language of lay audiences promoting risk comprehension**
 - a. A risk estimate where the measures are sub-clinical. For example, what does it mean to have a perturbation of your endocrine system as a result of an endocrine disrupting pesticide (Diamanti-Kandarakis et al., 2009)?
 - b. What does a slight deficit on a test of memory mean for your actual health? Needs a very sophisticated (in design) but simple (in presentation) explanation (Harari et al., 2010)
 - c. Explaining complex and ambiguous research findings to participants through face-to-face meetings, visual displays (e.g., exposure pathways for children through pictures), and community based participatory research (Morello-Frosch et al., 2009; Quandt et al., 2004)
 - **For understanding potential risks for individuals to promote protective behaviours**
 - a. *Interpreting research data*: How to interpret and act upon exposure data results (i.e., biomonitoring data) in order to prevent potential risks (Morello-Frosch et al., 2009)
 - b. *Interpreting uncertainty*: How to interpret the risks of nano-particles in chemicals when the science is still being developed (Albrecht et al., 2006)
 - **For understanding research findings for pesticide users to assess the benefits in relation to the risks**
 - a. How to interpret the benefits of pesticides containing nano-particles in relation to uncertainties with health effects (Albrecht et al., 2006)
 - b. How to assess the risks and benefits of using DDT for vector control and malaria risk reduction (Rogan and Chen, 2005)
 - **For assessing realistic and implementable strategies available for individuals to manage risks**
 - a. Use of PPE most common recommendation for pesticide exposure reduction but unrealistic in hot climates and poor countries where access is problematic (Nicol and Kennedy, 2008)
 - b. Community acceptability of rat traps to reduce exposures to neurotoxic pesticides in poor communities (Roomaney et al., 2012)
 - c. Banning of highly hazardous pesticides when managing through regulations fails to reduce poisonings (Roberts et al., 2003)
 - **Providing informed lay audiences through individual-level exposure results for study participants**
 - a. Participants in research studies require access to their individual results and simple means (graphs, colours, numbers) of what their results mean for their health and in relation to the other study participants' results (Morello-Frosch et al., 2009; Quandt et al., 2004)
-

pesticide policies and registration of pesticides are based on risk assessments submitted by industry when registering a pesticide. These assessments rely heavily on expensive experimental toxicology studies predominately conducted by industry who have a direct vested interest and who can afford to conduct these tests. Many of these studies are conducted in developed countries which use healthy European males as the extrapolation reference. What are needed are pesticide registration processes that include epidemiological studies of human health, particularly from the context and countries within which these pesticides will be used. What further exacerbates the situation for developing countries is

that decision-makers do not have the capacity or time to search for the latest research on neurotoxicity and pesticides, let alone grapple with interpreting the results (Rother, 2006, 2011; Eddleston et al., 2002). Not only can researchers provide relevant research findings for assessing toxicological (and specifically neurological) risks, but they can interpret risk estimates in an understandable manner which decision-makers often are not skilled or trained in interpreting.

On the other hand, the end-users of pesticides and the general public require findings and the ability to understand these in order to promote risk reduction behaviours (i.e., understanding why to

prevent exposures; Table 3). These findings are often presented in the form of risk communication materials (e.g., pamphlets, advisors, information insets, posters, radio/TV messages) or feedback to study participants (Quandt et al., 2004).

A “lay audience” is not a homogenous group. For example, “the general public” who have access to internet and have a secondary education will understand, access and process information differently from “the general public” who live in remote areas or are slum dwellers, have no access to the internet, do not have English as a first language and who have not completed a secondary education. Therefore lay target audiences need to be stratified into different categories outlining the level at which the research findings should be pitched. Although there are some resources on the internet for researchers to improve their research findings communication skills so as to write in plain language of the target audience (e.g., the Massive Open Online Course [MOOC] in communication or the National Institutes of Health Plain Language Online Training <http://plainlanguage.nih.gov/CBTs/PlainLanguage/login.asp>), there is little in the way of how to communicate to farmers and farmworkers exposed to pesticides, especially in a developing country context (e.g., face-to-face communication; Mgbenka et al., 2013; Brown et al., 2010; Quandt et al., 2004). The literature refers to the need for “transparent” information, formats and risk analyses which sounds good but ensuring “transparency” for different target audiences is a skill that is not generally taught to researchers (Bodemer, 2012; Fitzpatrick-Lewis et al., 2010; Kurz-Milcke et al., 2008). This could even conflict with academic requirements as in order to get promotion most academic institutions will not weight this kind of scientific output as valuable as a peer reviewed publication. Kurz-Milcke and colleagues (2008), illustrate how the format presentation of research findings (i.e., natural versus relative frequency or absolute versus relative risk bars) influences whether the data is transparent – that is, understandable – to the general public or not, and ultimately whether the general public is truly informed or not. The onus is thus on researchers to present scientifically sound information (e.g., that has been peer-reviewed) in formats that are comprehensible for the relevant target audience. After which the information must be presented in a non-confusing and understandable format.

3.2.2. Communication methods

A key barrier to disseminating research evidence to decision-makers is the lack of viable communication mechanisms, platforms and channels. Hyder and colleagues (2011) encountered this barrier after interviewing policy makers in low- and middle-income countries in regard to their attitudes towards research in general and particularly to using health research to inform health policy. The crucial issue is the lack of consistency in communicating research findings, no protocol for communication mechanisms, or at the very least, succinct guidance. Modes of communicating research findings differ for the target audience and need to be tailored appropriately for the audience and purpose (Rother, 2005; Bier, 2001). Table 1 lists the mechanisms identified as communication vehicles for decision-makers by various communicators; namely – policy briefs, risk assessment data, journal articles, media accounts, web based information and findings and discussion forums. As Hennik and Stephenson (2005) rightly point out, decision-makers are also not a homogenous group and that findings have to be structured and presented to take into account that policies, decision processes and department/ministry processes vary.

Key methods for communicating research findings in a meaningful way to end-users and the general public include: print information (e.g., pamphlets, brochures, fact sheets/frequently asked questions, posters; Rubin et al., 1997; Fitzpatrick-Lewis

et al., 2010), media approaches (e.g., newspaper articles, radio and television programmes, billboards, radio, web-based – social media), and interaction with researchers (face-to-face; community meetings; phone calls; presentations; O’Fallon and Dearry, 2001) (Fitzpatrick-Lewis et al., 2010; Stryker et al., 2008). Based on a systematic review of literature communicating environmental health risks, Fitzpatrick-Lewis and colleagues (2010) found that print information and media approaches were the favoured methods of communication by researchers. What the review did not evaluate was the comprehension level achieved with each communication method, particularly in developing countries, which may well reveal different results. Current thinking is that communication methods that are interactive, particularly face-to-face, provide a better forum for checking and ensuring comprehension (Mgbenka et al., 2013; Brown et al., 2012; Quandt et al., 2004). Further research is required on assessing the array of research dissemination methods that are available and appropriate for different contexts.

3.2.3. Risk communication formats

This section refers to the way into which the information is presented which dovetails the communication methods and refers to the actual way the findings are presented. There is extensive research on risk communication formats for clinical patients, but there is little in the way of packaging research findings particularly for a developing country context. Researchers should be trained in various risk communication formats as using an ill designed format for the target audience is a significant barrier (Grimshaw et al., 2012; Connelly and Knuth, 1998).

Decision-makers often require findings – “evidence” – packaged in a way that makes sense, is not confusing and upon which regulatory decisions can be made. In developed countries there is a movement for “transparent” health research findings, which refers to information and findings that do not confuse or are difficult to understand (Garcia-Retamero and Galesic, 2013). For example, Kurz-Milcke and colleagues (2008) researched on graphical presentations of findings (e.g., tinker cubes for frequencies, bar graphs) and illustrated how presenting the data differently but through the same format changes the transparency of the information.

Risk communication formats for pesticide end-users and the general public need to be culturally and context specific taking into account cultural beliefs, social contexts, language, levels of literacy and commonly used communication methods. For example, Quandt and colleagues (2004), after extensive research into the best approach, reported research findings to participants through face-to-face meetings in Spanish. Whereas Rother (2008a) found farmworkers interpretations of pesticide label pictograms designed for low literate populations were predominately misinterpreted and even at times provoking a greater health risk based on the interpretation.

3.2.4. Comprehension skills required

Access to research findings and making sure this information is noticed are crucial first steps, but without comprehension, the information provided will be of little consequence. The reality is that scientific results are complex to understand and the target audience may well have misconceptions about the subject matter and thus not understand the level of risk (Bier, 2001). Furthermore, decision-makers and the public require different skills in order to understand the information that will ultimately lead to a policy or behaviour change (Table 1). The former require numeracy, technical literacy and risk-benefit analysis skills (to highlight the key ones), whereas the public require basic to technical literacy skills, visual literacy particularly if icons and symbols are used, and health literacy (i.e., being able to decipher the difference between short and long term risks). Researchers presenting research

findings to the different target audiences need to take into account these different skills required in order to tailor the results in a way that promotes comprehension and the right-to-comprehend. Although ideally decision-makers should receive training to improve their own technical capacity to understand research findings (Hyder et al., 2011) resources and time are limited. Thus, the question arises as to whether the onus on producing comprehensible research findings should be the responsibility of the researcher when presenting their findings.

3.2.5. Action expectations

The action expectations (Table 1) for decision-makers and the public also vary. That is, the purpose for which the findings will be used should influence the way in which the information is presented and how it is understood. Providing access to neurotoxic research findings (e.g., “right-to-know” for study participants; Brody et al., 2007) is not enough to provoke risk mitigation actions and researchers should be instrumental in ensuring that findings are provided in a manner or through a process which promotes and facilitates the “right-to-comprehend” this information (Rother, 2011; Rother and London, 2008). Linear provision of information promotes access to information but does not ensure that the target audience understands the information (1) as intended and (2) in a manner in which a policy or behaviour change can be implemented. Even when the means are provided for understanding the information (e.g., training, face-to-face verbal explanations) the reality is that behaviour change is difficult to predict and control, and the timing of the action taken may not occur immediately.

The bottom line, as highlighted by Morgan and colleagues (2002: 182), is that “effective and reliable risk communication requires empirical study.” The benefits are multi-fold as illustrated in Fig. 1, but implementing a process of effective risk communication is complex.

3.3. Communicating research findings to decision-makers

The goal and interests of researchers investigating pesticide neurotoxicity does not always match the goals and interests of pesticides decision-makers. To overcome and address this, a process of dialogue is required. Through a series of workshops with West and Central African researchers and decision-makers, a key finding that emerged was that there is an absence of formal structures for regular consultation and interchange between researchers and decision-makers to align goals and needs (Ndiaye, 2009). Yet, as Hennik and Stephenson (2005) stress, collaboration is vital for effective development of research informed policies. Practically the question is who is responsible for starting such collaborations? Another issue to address in such collaborations is the vested interests of each for the outcomes (i.e., research/peer recognition versus policy development/political gain).

Language barriers, predominantly technical and discipline-specific, are another barrier for decision-makers to use of neurotoxic research findings. Researchers use academic jargon and theoretical concepts that are not relevant or incomprehensible by many decision-makers (Hyder et al., 2011; Hennik and Stephenson, 2005). This raises again the question of who is responsible for making findings used for policy making accessible and comprehensible for decision-makers or should the focus be on building the capacity of decision-makers to understand technical research findings?

The political context – for example, legislative and parliamentary processes, budget constraints, political agendas – and a lack of political will are also important points highlighted in the literature which impact on whether research findings are integrated into relevant policies (Hyder et al., 2011; Schillinger, 2010; Ndiaye, 2009; Hennik and Stephenson, 2005; Aaserud et al., 2005).

Although researchers are unable to control this context, they are able to be cognisant of the political context when making recommendations and presenting research findings. This is particularly important in developing countries.

The timing of dissemination of research findings can also conflict with the needs of decision-makers. Researchers often are focused on promotion, career development and on publishing in academic journals which tends to require research over a long period of time. This time frame is not pragmatic for decision-makers who seek short-term and quick solutions (Ndiaye, 2009). Although the benefits of disseminating research findings have been acknowledged, concerns have been raised by researchers in regard to premature dissemination of findings; particularly, contamination of findings, not following scientific methodological processes and subjecting research to peer criticism, and with consequences for publications and future funding (Israel et al., 2005).

Another important issue in addition to researchers taking note of how the package and disseminate their findings is that researchers need to review the quality of recommendations made in their publications. As Ndiaye's (2009) research highlighted, recommendations made by researchers are often viewed by decision-makers as too general and not pragmatic enough. Perhaps, Lomas' (2000) suggestion that early and continuous involvement of the relevant decision-makers in the development of the research proposal and during the data collection is a good predictor for the results being relevant and used as well as assisting with researchers developing implementable and appropriate recommendations.

3.4. Communicating research findings to end-users and/the general public

There are two key aspects to communicating research findings to end-users and the general public. These are (1) providing information versus ensuring the information is understood and, (2) general versus specific information. When communicating potential health risks, one cannot control what the public does with the information. Thus access to this information could promote a desired change, could cause increased anxiety and stress, or could have no effect due to numerous reasons. As Quandt and colleagues (2004) point out, models used for communicating risks to farmworkers tend to focus on more general risk information rather than specific research findings. Wilson and colleagues (2010) present various conceptual frameworks for disseminating research findings, but their review highlights that the methods are theoretical rather than practical. As illustrated in Table 1, key information for the public needs to be focused on promoting risk mitigating behaviours, but a vital first step is promoting environmental and health justice.

3.5. Communicating scientific uncertainty

There are times when research findings are inconclusive or there is inconclusive evidence around the neurotoxic health effects associated with particular pesticides and their cumulative effects (e.g., that low-level organophosphate exposures leads to neonatal neurotoxicity; Phillips, 2006; or that many pesticides cause neurotoxicity; Bjørling-Poulsen et al., 2008). How do decision-makers and the public operate within this realm of uncertainty and what role do researchers play in guiding decision-making with their findings? As is illustrated in this article, researchers play a key role in deciphering research findings, but researchers also play a key part in explaining uncertainty.

Scientific uncertainty has a role to play in evidence-based policy making and risk management but this is a complex matter raising ethical concerns. As Tannert and colleagues (2007) point out

“uncertainties challenge the central claim of science: that all problems are presumed to be solvable by research” (p. 895) requiring contemplation of ethical issues in relation to research limitations on assessing human health risks.

As *Bashers* (2001) points out, the focus in research on reducing uncertainty results in underdeveloped methods and processes for managing uncertainty and particularly the role researchers' findings play in this. Decision-makers' access to findings from a variety of sources, with both positive and negative results, is needed to facilitate the process of uncertainty management (*Renn, 2008*). Thus the framing of the findings is important (*Leiss and Powell, 2004*).

4. Case study

A case study of the use of highly neurotoxic street pesticides to control poverty-related pests in South African townships highlights the complexity of communicating neurotoxicity health risks to decision-makers and pesticide users (*Rother, 2010*). Street pesticides fall into two categories: legally registered pesticides, and non-registered substances. Legally registered pesticides are intended predominately for agricultural use, but are decanted into commonly-used beverage containers and sold unlabelled by informal vendors for the control of domestic pests such as cockroaches, rats, bedbugs, flies, and ants in urban areas. Found as a concentrate, diluted with water or as a cocktail of active ingredients, the most common active ingredients include the neurotoxins: methamidophos, cypermethrin, chlorpyrifos and aldicarb. The second category, non-registered substances, are often packaged products, such as insect chalk and powder insecticides, not legally registered for use in South Africa and sold by informal vendors. The ingredient in the cockroach powder is the organophosphate, acephate, another neurotoxin.

Accurate data linking child poisonings to street pesticides is confounded by reporting practices. When bringing a child for medical care, caregivers indicate the involvement of a pesticide in general terms, for example, rat poison or cockroach killer. As a result, when filing out the case report, health care professionals tend to record the pesticide as a commercially-available, legally registered pesticide. Research has identified the silent public health problem of children being acutely poisoned by street pesticides, resulting in hospitalization, intensive care treatment

and sometimes death (*Rother, 2008a, 2010, 2012; Balme et al., 2010*). Children are at increased risk of poisoning because of the similarity of the appearance of these products and their packaging to water or milk, the accessibility of these products in homes, small children's hand to mouth behaviours, and the vulnerability of being physically smaller.

The research questions raised in this case were:

- 1) To what extent are street pesticides linked to child poisonings?
- 2) How should these risks be communicated?

To identify cases involving street pesticides and use prevalence, the research team used a multitude of methods (*Rother, 2010*). These included collecting and testing samples of street pesticides, reading through the case reports of children poisoned by pesticides to decipher from the physicians' text where the product was purchased, collecting of narratives from caregivers while a poisoned child was being treated, and conducting a household survey ($N=200$). The data collected through these methods provided evidence that children were being poisoned by street pesticides and that these products are accessible and highly used. Surveillance is vital since poisonings from street pesticides are not properly recorded or reported, but the challenge of how to identify and report on an unlabelled product remains. The difficulty became relaying these findings to decision-makers and end-users as to prevent future acute poisonings, and the risk of long-term neurodevelopmental and neurobehavioral effects.

Pesticide poisoning in South African constitutes a notifiable medical condition and yet without correct diagnoses of poisoning from a street pesticide, decision-makers are unlikely to receive adequate data to inform policy. The researcher thus devised a few strategies to assist in collecting the data, for example, through a point chart to identify products households used, especially unlabelled street pesticides, and bringing this public health concern to the attention of decision-makers through presentations, policy briefs, journal articles, media coverage and pesticide end-users through the distribution of pamphlets at hospitals, stickers, radio coverage, articles in popular media, TV reporting), as well as promoting better reporting of poisonings. These were part of a risk communication strategy based on the research findings (*Table 4*). These were developed in several local languages for distribution at medical facilities and by Environmental Health Practitioners

Table 4
Examples of case study research findings linked to communication strategies.

Findings	Risk communication strategy
<ul style="list-style-type: none"> • Identification of street pesticides active ingredients through laboratory tests 	<ul style="list-style-type: none"> • Poisoning algorithm with point chart for health professionals for improved surveillance and reporting to decision-makers • Policy briefs for decision-makers • Poisoning prevention pamphlets in local languages for distribution at clinics and hospitals • Peer reviewed publications • Media – radio, TV, newspapers • Sticker in local languages recommending alternative rat control and avoidance of using Aldicarb • Presentations to health care professionals, community health care workers, environmental health professionals, decision-makers, NGO's, inter-governmental agencies
<ul style="list-style-type: none"> • Child poisoning statistics from case reviews and narratives • Household survey results 	<ul style="list-style-type: none"> • Policy briefs for decision-makers • Poisoning prevention pamphlets in local languages for distribution at clinics and hospitals • Peer reviewed publications • Media – radio, TV, newspapers • Presentations to health care professionals, community health care workers, environmental health professionals, decision-makers, NGO's, inter-governmental agencies
<ul style="list-style-type: none"> • Rat trap acceptance findings 	<ul style="list-style-type: none"> • Sticker in local languages recommending alternative rat control and avoidance of using Aldicarb • Media – radio, TV, newspapers • Presentations to health care professionals, community health care workers, environmental health professionals, decision-makers, NGO's, inter-governmental agencies

(government employees) who are tasked with educating community members on the risks of street pesticide and using alternative control measures (e.g., rat traps; Roomaney et al., 2012).

Although this example focuses on the case of South Africa, street pesticides are commonly used in other developing countries and reported use has been documented in cities in Zimbabwe, Tanzania, Mozambique, the United States of America, Brazil, the Dominican Republic and Israel (Rother, 2008b; Vates and Osterhoudt, 2008; Byrd et al., 2007; Nelson et al., 2001; Allen, 2001; Landrigan et al., 1999; CDC, 1997; Lifshitz et al., 1997; Lima and Reis 1995). Therefore, the findings of this study have a potentially larger impact than just for South African decision-makers and pesticide end-users. Thus the challenge is ensuring a large scale dissemination of the research findings and risk communication tools that were developed by the project team. This raises another issue: should research findings only be translated for decision-makers and the public within the country of the research? Again, it is up to researchers to assess the scope and relevance of their findings. The difficulty, however, lies in the lack of available platforms for researchers to communicate widely, other than through peer-reviewed publications.

5. Recommendations

While there is increasing agreement in the research community for the need to disseminate accessible research findings to lay audiences, what is lacking are measures to support this need through a coordinated, systematic and regular process for all researchers working on pesticide neurotoxicity. To increase the accessibility and dissemination of pesticide risk research, several recommendations are presented which approach the problem through multiple actors including researchers, academic institutions, ethics boards, funders, professional societies and communication specialists.

5.1. Researchers' responsibilities

Researchers have been identified as key actors in improving the accessibility of risk findings. Hyder and colleagues (2011) found that policy makers participating in their study advocated a key role for researchers in bridging the communication gap. This necessitates training for researchers on dissemination of findings to lay audiences, including decision makers. Additional training can be provided in several ways. Postgraduate training for health professionals and researchers could include training in translation of research findings (i.e., translational science, transfer of knowledge) and communication mechanisms. Professional societies, such as the International Congress for Occupational Health (ICOH), could provide translational workshops for academics, researchers, post-doctorates and students, covering a range of skills training including, how to write research findings into a policy brief, GRiPP methods, risk communication methods/skills, and transparent communication methods/skills. In order for this recommendation to be effective, a process to support research dissemination needs to be in place.

5.2. Processes to support research dissemination and understanding

While the translation of research findings into forms that are accessible to the lay public is important, dissemination processes and mechanisms to promote understanding are equally important. Building the capacity of researchers to disseminate (Orton et al., 2011; Hyder et al., 2011), and decision-makers and the general public to understand and use neurotoxicity research findings is thus key. This could be supported through initiatives such as establishing a clearinghouse where research can be

accessed through the internet, or through increasing contact between policy makers and researchers such as establishing forums where policy makers can discuss findings with researchers (Hyder et al., 2011; Hennik and Stephenson, 2005) or inviting policy makers to special forums at conferences, such as ICOH, where researchers present their pesticide research findings in an interactive and jargon-reduced environment. For end-users and the general public, research findings should also be made accessible through awareness raising campaigns, distributing public health advisories and other public communication mechanisms such as health care staff, radio and TV programmes. Essential is that these mechanisms promote opportunities for the lay public to ask clarification questions and challenge research findings. Thus this dissemination process needs to be interactive and not a top-down approach.

Another recommendation is that the current academic reward system be altered to evaluate research not only by traditional metrics but also by how well the results are communicated to a lay audience. Tracking the impact of this knowledge transfer could become an additional field of risk communication research in its own right. While there is interest in academia in translational research and evidence-informed policy making, reward for these is limited. Without additional reward or funding for translational research, many researchers will simply complete their research, publish and move on to the next study. Funders can influence the growth of translational research by withholding funding from projects that lack a clear commitment to translation of research findings. Several studies cited in this article received funding specifically to translate the research findings. There are efforts to promote translation of research for clinical applications (e.g., USA's National Institute of Health's efforts in creating translational science programmes, the European Commission's "European Advanced Translation Research Infrastructure in Medicine programme"), but these need to be built upon to reach lay audiences and decision-makers. Funding of translational research could promote the process and also finance what can be a costly process.

5.3. Promoting dissemination through ethics review boards

Poor risk communication can be as problematic as no risk communication warranting the need for preventing unmonitored distribution of scientific results (Leiss and Powell, 2004). Thus, university ethics review committees could require researchers not only to indicate who they will submit their research findings to, but also to provide a detailed account of how the findings will be distributed and formulated into non-academic channels.

A suggestion is that communicating neurotoxicity risks to at-risk populations not only be conducted in CBPR research projects, but in all research designs. As a first step, researchers should evaluate that their recommendations made in research publications are concrete, and provide relevant and implementable advice for both decision-makers and the general public. A recommended approach for dissemination, dependent on target audience, and scrutinized by experts on ethics boards, would require expertise on the part of adjudicating board members. This should be seriously considered within the research and ethics review community since, as Brown et al. (2010) have illustrated, there is ethics review board resistance to releasing research findings to lay populations for fear of the negative impact these results may have amongst a non-scientific community. Yet through engaging with researchers and ethics boards, Brown et al. (2010) have illustrated the positive effects of risk communication and furthering communities' right-to-know. If ethics boards were instrumental in overseeing the access to information process, they could also play a role in supporting a process for the right-to-comprehend this information. Thus

providing guidance to researchers and having a peer-reviewed process for risk communication mechanisms is crucial and worthy of further investigation.

5.4. Use of risk communication specialists and knowledge brokers

Rather than increasing the responsibilities of researchers, knowledge brokers, specialists in bridging the translation of researchers' findings for decision-makers to use, could translate pesticide neurotoxic research findings for evidence-based policy making (Kammen et al., 2006). This, however, is a costly process that will only occur in select situations and is even less likely to occur in developing countries. An alternative would be for communication specialists to form part of research teams. This would begin to address the issue of researchers needing extra training and communication skills while still ensuring appropriate translation of findings is occurring. However, until funders, ethics committees and professional bodies make the involvement of communication specialists on a research project mandatory, translation of research is likely to occur only occasionally.

Although this article focused specifically on communicating pesticide neurotoxicity risks, the issues highlighted and recommendations made are applicable to communicating other health risks.

6. Conclusion

While professional risk communication specialists focus on communicating information on various technological, health, and environmental risks and risk reduction or mitigation mechanisms to decision-makers or end-users, there are many more researchers generating such findings. These, however, are not trained risk communication specialists or do not work with professional risk communicators or knowledge brokers. The result is a vast amount of research produced globally which remains predominately in academic journals, institutions and conference proceedings. The issue then is how to foster a process whereby researchers, particularly in developing countries, can appropriately package findings and disseminate them to a broader target audience in order to reduce and prevent neurotoxic health effects associated with pesticide exposures at the level of policy and the individual. Having discussed the diverse audiences that must be addressed when communicating research findings, this article challenges researchers, the research community (including ethics boards and funders), and professional societies to take more responsibility for disseminating research findings to non-academics. This type of engagement has the potential to create benefits for all parties involved including the attainment of research accolades, effective and relevant policies implemented, and improved exposure reduction behaviours.

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Conflict of interest

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