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Abstract

Prevalence-induced concept change describes a cognitive mechanism by which someone's definition of a concept shifts as the prevalence of exemplars of that concept changes. For instance, in a task where people have to judge whether the colour of an ambiguously-coloured dot is blue or purple, if the frequency of objectively blue dots in the environment decreases, people expand their concept of blueness and judge more dots to be blue than they did initially. In a series of experiments, Levari et al. (2018) demonstrated that this phenomenon extends to higher-order decision-making, such as ethical judgments as well. What these findings suggest is that conceptual spaces (whether it's about colours or ethical statements) in humans are not fixed, but are sensitive to change. While Levari et al. (2018) established this phenomenon in young adults, it is unclear how it affects older adults: do they outsource control and become more susceptible to concept change or are they rigid enough in their beliefs to be resistant to it? In the current study, we explore how prevalence-induced concept change affects older adults' lower-level, perceptual, and higher- order, ethical, decision-making. We find that older adults are less sensitive to prevalence-induced concept change than younger adults across both domains. A computational model reveals that these differences might in part be explained by older adults' tendency to perseverate (repeat responses). Our results suggest that older adults' concept space may be less flexible than younger adults' when faced with a changing world.

Keywords: concept change; concept creep, ageing; judgement; sequential decision-making; modeling

Introduction

By 2068, almost 30% of the Canadian population will be 65 years or older (Statistics Canada, 2019). This demographic change is accompanied by a parallel decrease of working-age people to near 60% of the population. Together, these changes demonstrate that older adults are slated to take on an important role in shaping Canadian society and largely influence the future direction of our country. As such, it is critical to explore whether and how the cognitive processes underlying decision-making change across age.

The focus of this paper will be one such mechanism: concept formation. In order to navigate the world, we must all use concepts. By concept, we mean some cognitive state that allows us to categorise concrete and abstract objects in the world (cf. Medin & Smith, 1984). These concepts range from basic perceptual ones, such as if a banana is sufficiently ripe to eat, to more abstract ones that inform our complex judgements about the world, such as whether behavior is morally acceptable or not.

Importantly however, we must often apply these concepts to a changing world. For instance, when stocks of ripe bananas run low, we should adjust our concept of ripeness to include bananas that are speckled. On the other hand, when instances of violent crimes decrease, we should not expand our concept of violent crime to include jaywalking. In a phenomenon that they term prevalence- induced concept change, Levari et al. (2018) detail how our concepts of the change, when faced with a changing world. Across seven studies, they found that as the number of exemplars of a given concept decrease in the environment, the boundaries for that concept expand such as to include exemplars that they would otherwise exclude. For example, the authors used a task where participants had to serially judge whether individual dots that vary on a spectrum between blue and purple are in fact blue or purple. When the relative frequency of objectively coloured dots in the environment were equal and consistent across the task (50% blue dots, 50% purple dots), peoples' judgements were relatively stable: if they judged a dot to be blue in the first trials, they judged a similar dot to be blue in the last trials. However, if the number of blue dots in the environment decreased over the task (50% blue dots in the first trials, but gradually shifting to 4% blue dots in the last trials), dots similar to those at first judged as purple were categorised as blue in the final trials. Put simply, when the prevalence of exemplars of a concept in the environment changes, so do the boundaries of that concept —indeed the concept itself changes; hence the term prevalence-induced concept change. Critically, Levari et al. (2018) showed that this change does not only occur for lower-level perceptual phenomena like colour perception, but indeed also arose in higher-order judgements. In Study 6 and 7 of their paper, they showed that prevalence-induced concept change also occurs for social judgements, as well as judgements about ethical scenarios; the implications being not only that a broad range of concepts, once formed, are not stable, but that they are subject to continuous change over time. This interpretation was also supported by a computational model applied to Levari and colleague's (2018) data by Wilson (2018), which quantified this concept change from a sequential decision- making perspective.

While work so far has shed light on a ubiquitous and pervasive cognitive phenomenon, it has focused on just one

homogenous group of participants, namely young adults. However, there are both intuitive and theoretical reasons to be interested in how prevalence-induced concept change affects older adults' judgements. Firstly, prevalence-induced concept change as a real-world phenomenon is assumed to take place over long periods of time, during which individuals have the opportunity to observe changes in the prevalence of exemplars and adjust their concepts accordingly. As such, those who we would expect to experiment the brunt of prevalence-induced concept change outside of the lab are older adults who have been alive long enough to change their concepts over time. In this sense, it is of obvious ecological interest to explore how older adults might be affected by this phenomenon.

Secondly, there are also compelling theoretical reasons to think that older adults differ cognitively from young adults in terms of how they make judgements and decisions. For instance, there is well-documented evidence that older adults differ with regards to executive function (Mayr, Spieler, & Kliegl, 2001), memory (Lezak, Howieson, Bigler, & Tranel, 2012), and processing speed (Kerchner et al., 2012), all of which are critical for proper judgements. Cognitive differences like these between young and old adults lead to specific predictions about the effects of prevalence-induced concept change in older adults. Namely, in this paper, we put forward the following two, opposing, hypotheses:

H1: Older adults are less sensitive to prevalence-induced concept change than younger adults
H2: Older adults are more sensitive to prevalence-induced concept change than younger adults

In the case of H1, previous work suggests that older adults have more difficulty learning from uncertain outcomes compared to younger adults (Nassar et al., 2016; Eppinger, Walter, Heekeren, & Li, 2013). In computerised tasks, this difficulty manifests as perseverative behaviour, whereby older adults have a tendency to repeat previous responses despite changes in the environment (Buckner, Nassar, Li, & Eppinger, in prep). This perseveration is an indication that older adults are less likely than younger adults to update behaviour, even when doing so would be advantageous (i.e., it would be more rewarding, as in the studies cited above). In terms of prevalence-induced concept change, perseverative behaviour is exactly the opposite of behaviour that would lead to a concept change. That is, repetition of past choices makes it less likely that a rarer category will be chosen after a shift in prevalence. Indeed, this is exactly what Wilson (2018) found when he computationally modeled prevalence- induced concept change. Here, a higher influence of past choice (βC) on current behaviour reduced prevalence-induced concept change. Thus, older adults' tendency to perseverate may reduce the effects of prevalence-induced concept change on their judgements.

In the case of H2, results from several recent studies suggest that older adults may be less able to converge on an accurate representation of the current state, particularly if these states are latent (not directly observable) and need to be inferred from experience (Eppinger, Heekeren, & Li, 2015; Hämmerer, Müller, & Li, 2014). To help compensate for this difficulty in distinguishing task states, older adults may outsource control to the environment rather than relying on (sometimes inaccurate) internal representations (Spieler, Mayr, & LaGrone, 2006; Lindenberger & Mayr, 2014). In the case of PICC, this tendency to outsource control from internal representations to the environment means that older adults should be more strongly influenced by past stimuli, rather than by a set representation of a given category (e.g., blueness). In the same vein, Wilson's (2018) model highlights an opponent process to the effect of past response discussed under H1, the effect of previous stimuli, βF, such that people with a high value on βF are more likely to choose the opposite of the past stimulus and, thus, demonstrate more prevalence-induced concept change. In this sense, it is plausible that older adults' tendency to outsource control to the environment —that is, to rely more on cues from task stimuli instead of their own internal representations of, say, the colour blue— increases their sensitivity to prevalence- induced concept change.

To tease these hypotheses apart, the current study utilised two of the same experimental paradigms as Levari et al. (2018) to explore how prevalence-induced concept change differentially affects older adults' judgements compared to younger adults. Our results support H1 by demonstrating that older adults are less sensitive to prevalence-induced concept change than younger adults in both tasks. Wilson's (2018) computational model was also applied to our data to reveal that older adults tend to repeat previous responses more than younger adults, again lining up with H1. Response times are also analysed to help elucidate the mechanisms underlying these observed age differences.

Method

We recruited 132 participants from the community and the university participation pool, 66 of which were older adults (60 years and older) and 66 of which were younger adults (between 18 to 35 years). All participants were English-speaking, free of neurological or psychiatric disorders, and free of any cognitive, motor, visual (e.g., colourblindness), or other condition(s) that would impede their performance. Twelve of these participants were excluded for failing to meet exclusion criteria. Thus the final sample was composed of 120 participants: 60 young adults (51 women; Mage = 21.75; sage = 2.28) and 60 older adults (47 women; Mage = 69.78; sage = 5.21). In each age group, participants were randomly assigned to either the decreasing prevalence condition or the stable prevalence condition, in a counterbalanced order. All participants were compensated $20 CAN or 2 participation pool credits for participating in the study. This study protocol was approved by the Concordia Human Research Ethics Committee (certification number 30011191).

Materials

Dots Task In the Dots Task, participants had to judge the colour of an individual dot presented on the screen. The task began with a series of instruction screens explaining the task to the participant. These instructions were followed by a practice block consisting of 10 trials, in which participants became familiar with the task. Data from practice trials were not analysed.

After the practice block, participants began the test trials. The task consisted of 800 total trials, divided into 16 blocks of 50 trials each. In the decreasing prevalence condition, the number of blue dots in the environment decreased as the number of blocks increased in a predetermined fashion. In the stable prevalence condition, the proportion of blue dots in the environment did not change; it was always .50. In both cases, blue dots were defined as any dot who's RGB value was between [0, 0, 254] and [49, 0, 205]. Purple dots were defined as any dot who's RGB value was between [50, 0, 204] and [99, 0, 155]. Dot colours were randomly chosen for each trial based on the number of trials per block (50) and the frequency with which blue and purple dots should appear on a given block (always .50 in the stable prevalence condition and varying in the decreasing prevalence condition).

Each trial, participants judged just one of these dots as being either blue or purple by pressing the 'A' or 'L' key on the keyboard. The flow of each trial went as follows: a dot was presented on the screen for 500 ms, a question mark appeared on the screen until participants made a choice, and a blank screen appeared for 500 ms. Thus, there were no differences in timing across participants, except that which would arise from differences in response times.

Ethics Task In the Ethics Task, participants had to take on the role of a member of an Ethics Review Board and judge whether fictitious research proposals were ethical or not (phrased as whether they would allow these research studies to be conducted or not). All research proposals were norm tested by Levari et al. (2018, see Supporting Online Material) to produce scores depicting how ethical people found the 273 proposals. These scores were used to bin proposals as unethical (80 proposals), ethical (113 proposals), or ambiguous (80 proposals). These bins were used to calculate the proportion of proposals that appeared in each block (including the practice trial).

Just as in the Dots Task, participants were first presented with instruction screens explaining the task to them. Following the instructions, participants completed a practice trial in which they judged a research proposal using the keyboard keys. In this task, they pressed 'A' when they would not allow a study to be conducted and 'L' when they would.

Following the practice trial, participants began the test trials. All proposals in the experiment were presented in black text against a dark grey background. The task consisted of 240 trials broken into 10 blocks. In the decreasing prevalence condition, the proportion of unethical, ethical, and ambiguous proposals decreased across blocks. In the stable prevalence condition, the proportion between the three types of proposals was the same throughout the task: .33.

Each trial, participants read a proposal and pressed 'A' or 'L' on the keyboard indicating whether they thought that the research should be allowed to be conducted on people or not. There was no time limit on this choice. Following the choice, a fixation cross appeared on the screen for 500 ms, followed by the next proposal.

Both the Dots and Ethics Tasks described above were taken from Levari et al. (2018). Both tasks were programmed in Python using the PsychoPy libraries. Task code is available upon request.

Computational Model

Wilson (2018) proposed that prevalence-induced concept change could be explained in terms of sequential decision making. He modeled Levari et al. (2018) data using the following equation:

$$p_t = 1 - \frac{1}{1 + exp(\beta_0 + \beta_f f_t + \beta_F F_t + \beta_c C_t)} \qquad \text{(Eq. 1)}$$

where p_t is the probability of classifying the current stimulus as blue or unethical, β_0 captures the overall bias for classifying the stimulus as blue or unethical, β_f captures the effect of the current stimulus, β_F captures the effect of the past stimulus, and β_c captures the effect of past response. F_t and C_t represent the exponentially weighted sum of past stimuli and past response respectively. These parameters are controlled by two other parameters, λ_F and λ_C, which dictate the rate of decay of the exponential weighting with larger values corresponding to slower decay (see Wilson, 2018 for more details).

This leaves six free parameters to be estimated (β_0, β_f, β_F, β_C, λ_F and λ_C), which can be accomplished from participant behaviour using a standard maximum likelihood approach (Daw, 2011). Of these parameters, β_F and β_C are of most theoretical interest. Higher β_F values for older adults would line up with H2 (greater effect of past stimuli), whereas higher β_C values would line up with H1 (greater effect of past response; greater perseverance).

All analyses were conducted in R and code is available upon request.

Results

Choice Data

From a statistical perspective, prevalence-induced concept change is understood as a three-way interaction between condition, trial, and stimulus strength, predicting responses. Thus, if older and younger adults differ in their sensitivity to prevalence-induced concept change, we would expect to see a four-way interaction between these three terms and age group (dichotomized as young adult or older adult), as well as different effect sizes for this effect within each of the age groups.

Indeed, this is exactly what we observe. Results from mixed-effects regressions are represented in Figure 1. In both tasks, there was a four-way interaction between age group, condition, trial, and stimulus strength (In the Dots Task: $\beta = 8.49$, SE = 0.37, $p < .0001$; In the Ethics Task: $\beta = 0.90$, SE = 0.25, $p = .0004$). We followed up on these regression analyses with two within-group mixed-effects regressions, using the same predictors as above in both tasks (except for age group). This revealed that the effect of prevalence-induced concept change—again represented here as an interaction between condition, trial, and stimulus strength— was much stronger in younger adults ($\beta = 25.74$, SE = 0.90, $p < .0001$) than older adults ($\beta = 17.44$, SE = 0.30, $p < .0001$) in the Dots Task and was only statistically significant for younger adults in the Ethics Task (βYoung Adults = 1.19, SE = 0.22, $p < .0001$; βOlder Adults = 0.21, SE = 0.14, $p = .1324$). Given the complexity of the interaction, interpreting the standardized regression weight itself as an effect size is difficult and uninformative. Rather, to illustrate this effect, take for instance judgements in the decreasing prevalence condition for a dot that is 33% blue (who's RGB value is [67, 0, 187]). In the first 200 trials, 19% of young adults and 30% of older adults considered this dot to be blue. In the last 200 trials however, 73% of young adults now considered the dot to be blue, whereas only 58% of older adults considered the dot to be blue. Similarly, for a research proposal that had a normed rating of about 33% ethical, 33% of young adults and 44% of older adults stated that they would not allow this study to take place, during the first 48 trials. In the last 48 trials however, 50% of younger adults now would allow this study to take place, in contrast to 42% of older adults in the last 48 trials who would allow the study to take place. These, admittedly anecdotal, examples demonstrate that when the prevalence of exemplars in the environment decreased, both young and older adults' concepts expanded to include exemplars they previously did not, but that this phenomenon occurred to differing degrees depending on the participants' age.

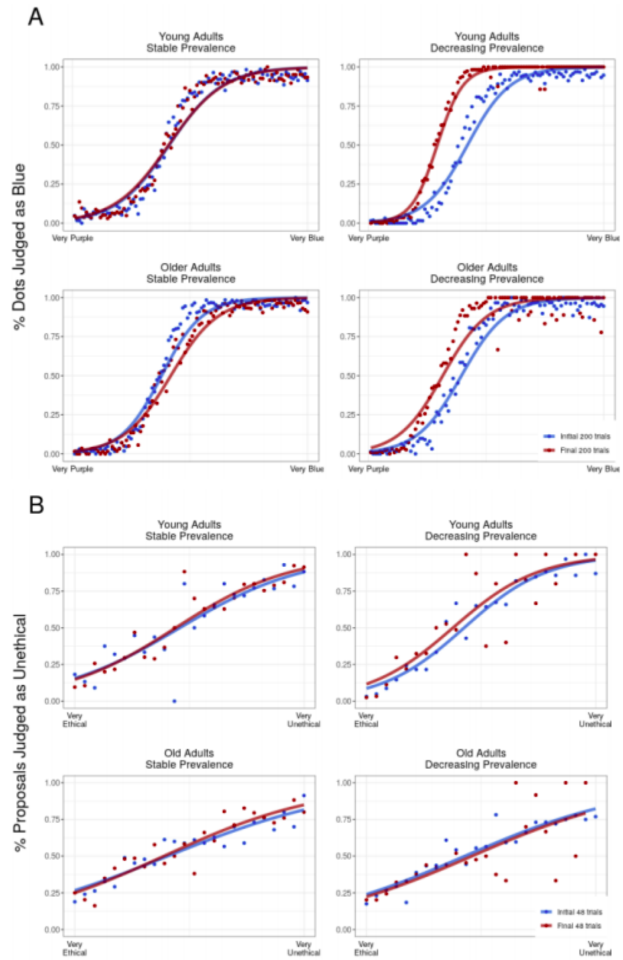

Figure 1: Concept judgements in (A) the Dots Task and (B) the Ethics Task. In the Dots Task, the y-axis represents the percent of dots judged as blue. In the Ethics Task, it represents the percent of proposals judged as unethical. The x-axis represents stimulus strength: blueness in the Dots Task and ethicality in the Ethics task. Curves represent fitted binomial regression curves. Blue points and lines represent the first 200 trials in the Dots Task and first 48 trials in the Ethics Task. Red lines represent the final 200 trials in the Dots Task and final 48 trials in the Ethics Task.

Computational Modeling Results

The most important results taken from the application of Wilson's (2018) model to our data regard β_C and λ_C in the Dots Task. They demonstrate that older adults have greater β_C values than younger adults, as well as greater values on the λ_C parameter, suggesting a slower decay of previous response.

We also found a main effect of condition and an interaction effect of condition and age group for both β_C and λ_C in the Dots Task. These findings suggest that β_C is greater in the decreasing prevalence condition overall and that this difference is greater for younger adults. The same is true for λ_C, except that this value is smaller in the decreasing prevalence condition for older adults compared to the stable prevalence condition.

No other notable differences between age groups were found in other parameters of the Dots Task or the Ethics Task.

Response Times

Response time data across age groups is presented in Figure 2. Two 2x2 ANOVA (age group x condition) were conducted on each subjects' mean response time data. These analyses revealed a significant main effect of age group on response time in both tasks (Dots Task: $F(1, 116)$: 51.05, $p < .0001$, 95% CI = [0.17, 0.34], $\text{difference}_{\text{Older - Young}} = 0.21$ seconds; Ethics Task: $F(1, 116)$: 23.47, $p < .0001$, 95% CI = [1.23, 4.04], $\text{difference}_{\text{Older - Young}} = 2.43$ seconds), but no statistically significant main effect of condition (Dots Task: $F(1, 116) = 0.34$, $p = .5633$, 95% CI = [-0.06, 0.10]; Ethics Task: $F(1, 116) = 0.12$, $p = .7208$, 95% CI = [-1.38, 1.43]) or interaction between age group or condition ($F(1, 116) = 1.63$, $p = .2040$, 95% CI = [-0.20, 0.04]; Ethics Task: $F(1, 116) = 0.15$, $p = .6904$, 95% CI = [-2.39, 1.59]).

All output for the model and behavioural results is available upon request.

Figure 2: Pirate plots of response times in both age groups across both tasks. Each point represents an individual participant's mean response time. Boxes represent 95% confidence intervals and horizontal lines represent group means.

Table 1: ANOVA predicting β_C and λ_C from age group and condition

Source	**SS**	**F**	***p***	**95% CI**
		$\boldsymbol{\beta_C}$		
Age Group	0.65	10.26	.0018	[0.08, 0.34]
Condition	1.86	29.35	< .0001	[0.22, 0.48]
Age Group * Condition	0.76	12.01	.0007	[-0.50, -0.14]
		$\boldsymbol{\lambda_C}$		
Age Group	0.96	9.62	.0024	[0.09, 0.41]
Condition	0.91	9.06	.0032	[0.08, 0.41]
Age Group * Condition	1.19	11.95	.0008	[-0.63, -0.17]

Note. ANOVA results for two key parameters of interest from the computational model. Average best fitting values for these parameters across age groups were as follows:
β_C: Older adults = 0.69, Young adults = 0.65
λ_C: Older adults = 0.51, Young adults = 0.45

Discussion

In this study we investigated how prevalence-induced concept change differentially affected the judgements of older adults across two conceptual domains: perception and ethics. We hypothesized that older adults would either be less sensitive (H1) or more sensitive (H2) to prevalence-induced concept change than younger adults. Our results support H1, demonstrating that older adults were less sensitive to prevalence-induced concept change in their judgements about the colours of dots and not significantly affected by the phenomenon in their ethical judgements about fictitious research proposals. We furthermore demonstrate that older adults are more affected by their previous responses than younger adults in the Dots Task, using Wilson's (2018) model.

These results dovetail nicely with a body of research demonstrating that older adults have greater difficulty than younger adults abandoning past behaviours in favour of new behaviours despite changes in the environment (Eppinger, Hämmerer, & Shu Chen, 2011). Wilson (2018) has suggested that the types of serial judgements where prevalence-induced concept change may affect judgments can also be thought of as a form of implicit learning. From this perspective, older adults may have more difficulty learning these latent states of stimuli and default to their original responses (Nassar et al., 2016). This interpretation would also line up with neurocognitive work, suggesting that deficient dopaminergic modulation of the prefrontal cortex's attention regulation mechanisms leads to less distinctive mental representations among older adults (Li, Lindenberger, & Sverker Sikström, 2001). This would further imply that as people age, their representations of past stimuli become weaker and less specific. Thus, due to this dysregulation of dopamine pathways, older adults may rely less on their (impoverished) representation of past stimuli and instead rely more readily on their previous responses (i.e., engage in perseverative behaviour; Eppinger, et al., 2013; de Boer et al., 2017). In this respect, it is rather interesting that a feature of healthy ageing generally regarded as maladaptive—perseveration, a difficulty adapting behaviour to changing conditions—would in this case be protective against some of the biasing effects of prevalence-induced concept change, at least at a basic perceptual level.

However, this is not the full story. Aside from perseveration, older adults' longer response times might also have contributed to reduced prevalence-induced concept change. As Wilson (2018) briefly remarked, the smallest effects in Levari's et al. (2018) original data were observed in the Ethics Task, in which participants also took the longest time to respond. This inadvertently increased the amount of time between stimuli across the tasks (approximately 850 ms between dots in Study 1-5 and 5 s between research proposals in Study 7). Our results replicate this finding in younger adults, as well as demonstrate a lack of effect in the Ethics Task in older adults, who also happen to also have even longer response times across both tasks. This is particularly interesting given that the behavioural differences observed between younger and older adults in the Ethics Task are not apparent in the parameters fitted by the model. Thus, the question arises: are the effects of prevalence-induced concept change observed in these tasks affected by the speed at which responses are made?

Answering this question is important both for better understanding how prevalence-induced concept change plays out in the real-world and for elucidating how it differentially affects younger and older adults' judgements. That is, real-world judgements are often made on "stimuli" that are hours, days, or months apart in time. As such, it is important to verify how robust the experimental effects are to differences in timing between stimuli should we wish to generalise from the lab to real-world decision-making.

Moreover, the observed differences in response times between younger and older adults might be explained by two different (but not mutually exclusive) hypotheses, which in turn might elucidate the mechanisms underlying the differences in sensitivity to prevalence-induced concept change. First, older adults in our sample might be exhibiting general slowing, a well-known cognitive phenomenon in healthy ageing whereby peoples' response times slow with age (Verhaeghen & Cerella, 2002). If this were the case, slower responses among older adults in our sample would be a natural, non-deliberate, result of healthy ageing. As such, it would be important to evaluate to what degree prevalence- induced concept change is sensitive to individual task's space between stimuli and if there were ways to measure it independently of response time. However, a second explanation as to why older adults differ in terms of response time from younger adults might be that they engage in a speed-accuracy trade-off (Starns & Ratcliffe, 2012). From this perspective, it wouldn't be the case that older adults in our sample are necessarily limited in their ability to respond quickly per se, but rather prioritise "accuracy" (or perhaps something like internal consistency in the case of the Ethics Task) over response speed. Were this the case, it would suggest that the effects of prevalence-induced concept change might be avoidable when deliberate effort is allocated to making accurate judgements. Furthermore, it would open up the possibility that the effects elicited by current tasks used to measure prevalence-induced concept change are not necessarily sensitive to increased response time in and of itself (i.e., greater distance between stimuli) but rather to different decision-making strategies altogether. We are currently working on teasing these competing hypotheses apart in two follow-up studies in young adults.

In summary, the current results suggest that older adults are less sensitive to prevalence-induced concept change than younger adults. The implication of these findings are context-dependent, such that in some cases it can be adaptive for one's judgements to be sensitive to a changing world, however in others it can be harmful. The results of this study simply point to the existence of age differences that merit further exploration, given the increased decision-making role older adults will come to occupy in our society in the near future. Furthermore, they provide a clear direction for future work to determine whether judgements are always subject to prevalence-induced concept change or if people can resist its effect when motivated to do so.

Though much more work needs to be done, the current study points to the fact that as we age, our judgements and concepts might become more rigid as we face a changing world. Indeed, as we age, it seems our concepts remain more stable, despite the world around us changing.

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