

Prospective and inhibitory intolerance of uncertainty, and certainty-seeking behaviours across adulthood in a Chinese sample

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ABSTRACT

Difficulties in coping with the unknown, or intolerance of uncertainty (IU), has been established as an important risk factor for anxiety and other mental health problems. However, the conceptualisation so far is primarily based on self-report data from younger populations. Informed by theories on both anxiety and aging, the current study examined self-report IU and behavioural decisions made under uncertainty, across adulthood. A total of 300 participants between the age of 20–79 years were recruited from the community. They completed the self-reported Intolerance of Uncertainty Scale (IUS-12) and the behavioural Balloon Analogue Risk Task (BART). Results suggested that young adults had higher self-report prospective IU than older adults, and there were no differences on IUS-12 scores between middle-aged versus young/older adults. However, older adults had higher certainty-prone behaviours on the BART (less pumps and bursts) than both young and middle-aged adults. Exploratory modelling analysis on the BART responses suggested that young adults had both lower loss aversion and lower sensitivity to risk changes in the environment. The results are discussed in line with previous theories; whilst one's belief about their general ability to manage uncertainty in daily life increases with age, so does one's behavioural conservatism in the context of new (i.e., uncertain) situations. The results have practical implications for working with adults of various ages, in terms of needing to tailor uncertainty management and emotion regulation to the developmental stage of the person.

1. Introduction

In daily life, we often have to make decisions based on inadequate amounts of information or in the face of uncertainty. Intolerance of uncertainty (IU) is a predisposition to respond negatively to ambiguous situations, or when having to make decisions based on incomplete information, characterised by an underlying fear of the unknown [1–3]. Current evidence indicates that IU is a key transdiagnostic risk factor underlying emotional dysfunction [4]. For example, IU predisposes individuals to anxiety disorders [2,5]. Furthermore, researchers have found that IU is heightened in individuals with depression, eating disorders [6–8] and schizophrenia [2,7]. However, current research on IU has mainly focused on young to middle-aged adults, with less studies on emerging young adults, older adults, and comparisons across adulthood. Some emerging studies indicated that IU is particularly disabling for the older population, too, and is related to worry, loneliness, and

hypochondriasis [9–12]. This issue was particularly alarming during the COVID-19 pandemic, as IU has been found to increase loneliness among older people [11], which is an established risk factor for physical health deterioration and even mortality among older people [13,14]. Furthermore, it has been argued that because many middle-aged and older adults hold management, leadership, and policy-making roles, it is also in the public's interest to better understand the possible changes in response to uncertainty across adulthood [12,15].

1.1. Theoretical basis and contribution to understanding anxiety and aging

Brosschot and colleagues [16] proposed the Generalized Unsafety Theory of Stress (GUTS), which placed uncertainty at the core of anxiety and stress. In particular, it proposed that anxiety/stress is caused by a lack of perceived safety arising from uncertainty in the environment,

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which is exacerbated under specific conditions. One of these conditions is older age, which is proposed to heighten the default generalized unsafety system, because uncertainty in the environment can be more threatening to one's survival. Therefore, based on the GUTS, the ability to deal with uncertainty is expected to decline with aging. However, as Brosschot and colleagues [16] pointed out, these ideas remain to be tested empirically, and older people's response in the context of uncertainty remains to be examined.

The Socioemotional Selectivity Theory for aging (SST) proposes that because older adults prioritise emotional wellbeing (while younger adults prioritise information for better future-preparedness), they may actively avoid new information, scenarios, or relationships [17]. It therefore also infers that older adults may avoid uncertainty. However, the SST also posits a positivity bias in older age, with older adults tending to self-report an overall positive affect and remember more positive events. Therefore, it is possible that older adults believe and report that they manage uncertainty well, whilst their behaviour might indicate otherwise.

The middle-age, which has been less studied in the anxiety and aging literature, has been found to be the point at which we experience the lowest well-being in life (e.g., lowest well-being was found to be at the age of 48.3 years across 477 countries in [18]). Among the literature on IU in samples including middle-aged adults, results support IU being a significant risk factor impairing mental health among middle-age adults [19,20]. Theories that postulate developmental changes in aging should also account for the perception and behaviours of middle-aged adults, as included in the current project.

1.2. A reduction in IU with age: possible self-perception bias

To date, questionnaire-based studies on age differences in IU and related psychological health have found that self-reported levels of IU, worry, and depressive and anxious symptoms among older adults were lower than those of younger adults [1,21,22]. A commonly proposed reason is that older adults may have more experience with reducing states of negativity, and therefore are better at regulating IU and worry [22,23]. However, previous research has suggested that self-report measures may reflect the participants' perception of their ability, which does not always translate to actual behaviour [24]. In looking at the behavioural consequences of IU, some research has found that self-reported IU levels are related to the behavioural tendency to over-seek information and are associated with risk aversion in general [25].

1.3. Behavioural measures of IU: certainty-seeking behaviours

The Balloon Analogue Risk Task (BART; [26]) is a promising behavioural measure for IU with high ecological validity [24]. In this task, participants are instructed to collect as many points as possible by inflating virtual balloons without bursting them. If the balloon bursts, no points are given on that trial, and an unpleasant sound is played. Researchers have suggested that BART is suitable as a platform for studying IU because of its emotion-eliciting nature (mild distress from the unpredictable and unpleasant sound), which provides higher ecological validity to mimic the sense of anxiety when confronted with making decisions under uncertainty in daily life [24]. The BART has been shown to be sensitive to capturing individual differences in IU (e.g., correlated with self-reported IU) in both healthy individuals and those with eating disorders or anxiety [6,27]. Maner et al. [27] found that American university students with higher self-reported traits of social anxiety, trait anxiety, or worry showed higher certainty-prone behaviours on the BART (i.e., less pumps per balloon or cashing in the balloons sooner). Thus, this task offers a behavioural measure that can mimic situations involving uncertainty encountered in daily life.

The BART has been used previously with adults of different ages. Schulman et al.'s [28] used the BART to study age differences in IU and did not find any difference between the young (18–30 yo) and older (60

yo or above) group in the performance on the classic BART (majority of the participants were described as non-Hispanic White). However, in that study, when the rule was changed, such that pumping was framed as preventing the loss of points, older adults took more risks than younger adults, but ended up with lower scores (as they popped too many balloons). Older adults, therefore, appeared to be affected by contextual information, such that they were overly anxious about loss prevention. The BART has been applied across different cultures, including among Chinese adults, although the research interest has mostly focused on the neural underpinnings of decision making, and the participants were mainly young to middle-aged adults (e.g., [29,30]). There is emerging evidence showing that Chinese older adults also show more loss aversion on the BART compared to younger adults [31].

1.4. Cultural context and subcomponents of IU

There has been emerging evidence showing potential cultural influence on the effect of IU on mental health. Whilst IU negatively affected life satisfaction in the Mexican and American samples, it was not the case for the Chinese sample [32]. The authors proposed possible cultural values in explaining this result, such as dialecticism of viewing positivity as an unstable state [32]. In a recent large survey study conducted in Hong Kong [33], subcomponents of IU showed differential roles; prospective IU (IUP) was found to be more associated with depressive and anxious symptoms than inhibitory IU (IUI). IUP has been conceptualized as the cognitive aspect of IU, whilst IUI represents the inhibitory anxiety associated with IU [34,35]. It was speculated that in Asian cultures, due to collectivism, one's behavioural decisions (e.g., inhibition/avoidance) are influenced by both a person's general tendency and approval from his or her social networks [33]. Therefore, more exploration into the manifestation and influence of sub-components of IU in non-Western samples could also further our understanding of IU.

1.5. Relationships with emotion regulation, general emotional and cognitive states

Previous research has reported age differences in general emotional state and cognitive abilities across adulthood. The relationship between IU and emotional difficulties (e.g., worries) was explained by emotion regulatory difficulties [36]. Therefore, we included emotion regulation and general emotional states in the study. For example, in line with the Socioemotional Selectivity Theory for aging [17], aging has been found to be associated with reduced negative emotions and an increase in emotion regulation abilities [37,38]. Cognitive functioning, especially executive functions, are associated with and implicated in emotion regulation, and can decline with aging [39]; therefore, these factors are also measured and controlled in this study.

1.6. Study aims and hypotheses

In summary, because the existing literature on IU is primarily based on young to middle aged adults, the results of the proposed research will contribute to the literature about healthy aging, in both midlife and older age, informing possible developmental changes in the perception and ability to manage uncertainty across adulthood. Together, this pattern of results could inform more tailored interventions for reducing mental health issues among both younger and older adults, considering the established role of IU as a trans-diagnostic risk factor for psychological dysfunction (e.g., Carleton [2]).

We aimed to comprehensively examine IU using both a behavioural task and self-report measures in a sample of young, middle-aged, and older adults. The overarching hypotheses were that 1) younger adults self-report higher IU than older adults, but 2) there would be a dissociation between self-perception and behavioural performance in both young and older participants. Specifically, older adults were expected to

report less IU than young adults, but may exhibit more certainty-seeking behaviours on BART (i.e., less pumps and less bursts) than their younger counterparts. No specific hypothesis was set for the middle-aged group due to the limited research available. Effect of the subcomponents of IU was exploratory in nature, also due to the relatively limited prior research for setting directional hypothesis.

2. Method

2.1. Research design

This project was preregistered with AsPredicted (#109817). This study adopted a 2 (high vs. low uncertainty) \times 3 (low vs medium vs high risk, within-subject factor) \times 3 (young vs middle-aged vs older adults) mixed-factorial design. The inclusion criteria were: aged between 20 and 79 years, understand Cantonese Chinese, and have basic computer skills. Those who reported a history of neurological or psychiatric conditions, colour weakness or colour blindness, and excessive fear of the burst of balloons were excluded during the initial screening. Participants were then randomly assigned to one of the two conditions (either high uncertainty or low uncertainty) using the randomized block design. During recruitment, we further divided the three age groups into six (20–29, 30–39, 40–49, 50–59, 60–69, and 70–79 years old) to ensure the age distribution was more evenly spread, hence more representative. Twelve blocks were then created (2 gender \times 6 age groups) to balance the gender ratio and age groups among the conditions. The six age groups were later regrouped into three when performing the data analyses, as planned. The randomization was carried out by a research assistant using Microsoft Excel and participants were unaware of the differences in conditions.

The planned sample size was 300 healthy adults (3 Age Group \times 100 participants). According to a prior power analysis using G*Power (power = 0.95, $\eta_p^2 = 0.13$ from a pilot study), a minimum sample of 107 participants would be required to detect main effects and Condition \times Age interactions in ANOVA. Considering the sample size of a similar study ($n = 254$ in [28]), and possible missing data, the target sample size of 300 was decided.

2.2. Participants

A total of 300 participants aged between 20 and 79 years ($M = 48.72$, $SD = 17.51$; $n = 295$ ethnically Chinese, $n = 5$ refused to give ethnicity) were recruited through posters on the university campus or by word of mouth. The gender ratio between men and women was 50:50 in each age group. The demographic information and their performance on the cognitive tasks are presented in Table 1.

2.3. Measures

2.3.1. Balloon analogue risk task (BART)

The modified BART version by Smith et al. [40] was adopted to assess the participants' certainty-seeking behaviours. This variation of BART consisted of two conditions: the high uncertainty condition, which was similar to the classic BART design by Lejuez et al. [26], and the low uncertainty condition, which provided participants with more information about the probabilities of balloon explosion.

For each participant, there were a total of 120 trials completed (60 trials for 2 blocks). To follow previous publication [40], the performance on the first 60 trials were analysed. In the 60 trials, participants were asked to pump 60 balloons (one balloon per trial). Each pump will earn participants five points in the temporary bank until the balloon explodes. To transfer the temporary points to the accumulated total score, participants had to click "Collect Points" before the balloon burst. Otherwise, all the points in the temporary bank will be lost due to the balloon bursting, as indicated by an explosive sound. Participants were asked to earn as many points as possible by maximizing the number of

Table 1
Demographic information, emotional state and cognitive assessment.

	20–39 ($n = 100$)	40–59 ($n = 100$)	60–79 ($n = 100$)	Total ($n = 300$)
Gender Ratio (Men/Women)	50/50	50/50	50/50	150/150
Educational Attainment				
Secondary School or below	0 (0.0%)	16 (16.0%)	59 (59%)	75 (25.1%)
Post-Secondary School or above	99 (100%)	84 (84.0%)	41 (41%)	224 (74.9%)
Monthly Personal Income (HKD)				113
Below \$10,000	40 (44.0%)	13 (16.7%)	60 (66.7%)	(43.6%)
\$10,000–19,999	16 (17.6%)	11 (14.1%)	16 (17.8%)	43 (16.6%)
\$20,000–49,999	30 (33.0%)	37 (47.4%)	11 (12.2%)	78 (30.1%)
\$50,000 or above	5 (5.5%)	17 (21.8%)	3 (3.3%)	25 (9.7%)
DASS (<i>SD</i>)				
Depression	3.40 (3.72)	2.39 (2.78)	2.02 (2.51)	2.60 (3.09)
Anxiety	2.81 (2.93)	2.40 (2.30)	2.18 (2.17)	2.46 (2.49)
Stress	5.11 (4.47)	4.41 (3.60)	4.25 (3.35)	4.59 (3.84)
Mean Cognitive Abilities (<i>SD</i>)				
Verbal Fluency	22.46 (5.16)	21.9 (5.57)	19.56 (4.94)	21.31 (5.36)
Animal				
Digit Span				
Backwards	6.54 (1.74)	5.71 (1.58)	5.53 (1.79)	5.93 (1.75)
Stroop Interference		11.05 (6.82)	15.04 (10.65)	11.37 (8.34)
Score	8.03 (5.04)	(6.82)	(10.65)	(8.34)

Note. DASS = Depression Anxiety Stress Scales. Only a valid percentage was presented. The numbers in educational attainment and monthly personal income did not always add up to the total number of participants due to missing values. There was no missing value in gender and cognitive assessment.

pumps before the balloon exploded.

Throughout the 60 trials, participants encountered three types of balloons: Blue, Purple, and Grey. Each colour is associated with different initial chances of explosion: Blue = 1/10, Purple = 1/20, and Grey = 1/40. The risk gradually increased as participants decided to keep pumping. For example, the first pump for a Blue balloon has a 1/10 chance of explosion, a 1/9 chance for the second pump, and a 1/8 chance for the third pump.

Participants in the high-uncertainty conditions were informed that the risk of explosion varies across different colours, but were not told the exact probability. As a result, they had to learn gradually across the trials about the chances of explosion associated with different colours. On the other hand, participants in the low uncertainty condition were informed about the exact probability of explosion for each colour through a visual indicator. In the top right of the screen, a number of balls corresponding to the initial chance of explosion were displayed (i.e., 10 for Blue, 20 for Purple, and 40 for Grey). Among these balls, one of them was labelled red and the remaining were green. Participants were told that for each pump, a ball would be randomly drawn from the array. If the green ball were chosen, the balloon would not explode, and that green ball would be removed. If the red ball was selected, the balloon would explode, and they would receive zero points for this round.

To measure the certainty-seeking behaviours, the adjusted average pumps and the percentage of bursts were computed for each colour using the 60 trials. The calculation for the two indicators was as follows: adjusted average pumps = average number of pumps in the intact balloon only; percentage of bursts = numbers of burst balloons / total numbers of balloons. A lower adjusted average pump and a smaller percentage of bursts indicate more certainty-seeking behaviours.

2.3.2. Intolerance of uncertainty scale – 12 items (IUS-12)

To measure the self-report level of IU, the IUS-12 developed by Carleton et al. [34] was used. It is a 5-point Likert scale and can be further divided into two subfactors – prospective intolerance of uncertainty (IUP) and inhibitory intolerance of uncertainty (IUI). IUP could be understood as the desire to predict future uncertainty, whereas IUI could be conceptualized as behavioural paralysis when facing uncertain events. The original version was found to be reliable and exhibited good convergent validity [34]. The Chinese version by Tsang et al. [41] was adopted ($\alpha = 0.84$), and it showed good reliability in the current study (IUS-12 total score: $\alpha = 0.82$, IUP: $\alpha = 0.71$, IUI: $\alpha = 0.85$). This translated version also showed good reliability in a large survey study among adults of various ages in Hong Kong (total score: $\alpha = 0.84$; IUP: $\alpha = 0.74$; IUI: $\alpha = 0.76$, [33]).

2.3.3. Emotional regulation questionnaire (ERQ)

The Chinese version of ERQ was a 7-point Likert which consists of 10 items [42]. It measures participants' tendency to adopt two types of emotional regulation techniques, namely cognitive reappraisal and expressive suppression. The Chinese version ERQ was proven to be reliable ($\alpha \geq 0.80$ for both reappraisal and suppression factors) and valid in the local context [42]. In the current study, the two factors also exhibited good reliability (Reappraisal: $\alpha = 0.84$; Suppression: $\alpha = 0.73$).

2.3.4. Depression anxiety and stress scales (DASS) - 21 items

The Chinese version of DASS-21, adapted by Moussa et al. [43], measures depression, anxiety, and stress in respondents, with each domain consisting of 7 items. The three subscales of DASS-21 have been used with various populations, including Chinese university students and general adults [44] and adults in Hong Kong [45]. In the present study, DASS-21 demonstrated good reliability in depression ($\alpha = 0.82$), anxiety ($\alpha = 0.74$), and stress ($\alpha = 0.83$) subscales and for the whole scale ($\alpha = 0.91$). These functioned as covariates in the analysis to account for possible differences in general emotional state of participants of different ages, and were not intended to examine the associations between IU with any specific mood disorders.

2.3.5. Cognitive abilities

To evaluate participants' cognitive abilities, the Chinese version of verbal fluency tasks, digit span backward tasks, and Stroop tests were administered to assess their executive functions [46]. These functioned as covariates in the analysis to account for possible differences in general cognitive state of participants of different ages.

In the verbal fluency tasks, participants were asked to name as many animals as possible within one minute. The more animals were named, the better the verbal fluency of participants.

In the digit span backwards task, a research assistant read aloud sequences of digits, and participants were instructed to memorise and report the digits in reverse order. The first trial starts at three digits. If participants correctly report the order, the task difficulties increase gradually as the numbers of digits increase in the subsequent trials until participants fail the same level twice. The highest numbers of digits successfully reported by participants were used to indicate their working memory.

For the Stroop test, it consisted of three parts – colour-dots, colour-words, and mismatched colour-words (e.g., the word red printed in blue colour) [46]. Participants were asked to read aloud the ink colour in all three parts as fast as they could. The Stroop Interference Score was then calculated as follows: time spent in completing the mismatched colour words – time spent in completing the colour dots. A lower score indicates fewer interferences, hence better inhibition.

2.3.6. Other variables

Information regarding the participant's age, gender, personal monthly income, ethnicity, and educational attainment was also

collected in a survey as potential covariates [47,48]. These variables were found to be affecting individuals' risk preferences [47,48].

2.4. Procedure

All the experiments took place in a quiet room inside the university campus. Participants were told to complete a set of self-reported questionnaires, a computerised decision-making task, and three cognitive ability assessments. Before the start of the experiments, participants were instructed to turn off their phones and to provide informed consent (with a digital signature using the laptop). Ethics approval was obtained prior to any data collection (HSEARS20220321004).

After completing the self-report measurements, participants were introduced to the computerised BART on a laptop. Participants were instructed to wear a headset and were informed in advance about the balloon explosion sounds. They were given five practice trials to familiarise themselves with the rules and operations. Once the participants completed all trials, their final scores would be displayed on the screen. To motivate participants to try their best, a small gift was given to those who scored above the average performance of the participants (collected during the pilot study). After finishing the BART, participants engaged in three cognitive tasks as instructed. At the end of the experiment, participants were debriefed, and each received a HK\$100 coupon for their participation.

2.5. Planned data analysis on age differences

Before the formal analyses, BART outliers were screened so that variables deviating from the group average by 2.5 SD would be excluded from the analyses. Additionally, because the calculation of the adjusted average pumps considered only pumps in intact balloons, three participants who busted all Blue balloons in the high uncertainty condition were thus excluded from the analyses. All the analyses were performed using Version 28 of the IBM Statistical Package for Social Sciences (SPSS).

To examine the age effects on IU, one-way ANOVA will be carried out to test how these three age groups differ in terms of self-reported IU. In addition, two sets of Mixed ANOVA will be performed using the adjusted average pumps and percentage of bursts as the dependent variables to investigate the age effects on task-specific IU. Age group, Condition, and Balloon Colour indicating risk level (within-subject factors) will be used as the independent factors. Gender (men/women), personal monthly income in HKD (below \$10,000, \$10,000-19,999, \$20,000-\$49,999, \$50,000 or above), education attainment (secondary school or below, post-secondary school or above), levels of depression, anxiety and stress scores, and cognitive abilities will be treated as the covariates. Dummy coding was applied when accounting for categorical covariates in the analyses.

To examine the relationship between self-report IU and certainty-seeking behaviours in BART, correlation analyses was carried out using IUS-12 (including total score, IUP, and IUI) and BART outcomes (i.e. adjusted average pumps and percentage of bursts) for each colour. To further verify their relationships, regression analyses were used to control for the effects of individuals' cognitive abilities, emotional state and demographic characteristics, as these were found to be associated with individuals' preferences for risk-taking (i.e., BART in our case) [33,34]. To explore the relationships between emotional regulation, and self-report and task-specific IU, correlation analyses were performed.

2.6. Exploratory modelling analysis

We used the exponential-weight mean-variance (EWMV) model [49] to examine latent cognitive variables underlying participants' decision-making in BART. This model includes five free parameters. Specifically, one's perceived probability that the balloon will burst on trial k

(p_k^{burst}) is determined by two parameters: prior belief of burst (φ) and updating exponent (η). The subjective utility for pumping a balloon is calculated based on p_k^{burst} , the amount of reward per successful pump, and two additional parameters: the risk preference (ρ) and loss aversion (λ). Finally, the utility is entered into a softmax function to calculate the probability that the participant will pump the balloon. Participants' decision randomness is determined by the inverse temperature parameter (τ). The details on the model can be found in the original study [49].

We estimated parameter values for each group using a hierarchical Bayesian approach based on Monte Carlo Markov chain (MCMC) sampling. We implemented the estimation using the hBayesDM package [50], which is based on R and Stan. We ran four independent chains, each with 4000 MCMC samples (including 1000 burn-in samples). The Rhat values were smaller than 1.1 for all groups, suggesting that the four chains had converged well. We used the posterior distributions of the five parameters for each individual to perform the between-group comparison.

3. Results

3.1. Association between self-report IU and certainty-seeking behaviours in BART

IUP significantly correlated with the adjusted average pumps ($r = 0.23, p < .01$) and percentage of bursts ($r = 0.16, p < .05$) of the Grey balloon under the uncertainty condition (Table 3).

To further confirm their relationships, multiple linear regression analyses were carried out to rule out the effects of individual cognitive abilities, emotional state, and demographic factors on BART behaviours (Table 2). Individual performances in cognitive assessments (verbal fluency task, digit span backwards, Stroop test), scores in DASS, and other variables (age, gender, personal income, educational attainment) were entered into the model, in addition to IUP. The results indicated that, for the Grey balloon in the low uncertainty condition, IUP remained a significant predictor for the adjusted average pumps ($\beta = 0.26, p < .01$). On the contrary, the effects of IUP on the percentage of bursts became non-significant when the above covariates were considered ($\beta = 0.11, p = .26$).

3.2. Emotion regulation and IU

There were significant correlations between emotion regulation skills and self-reported IU. Specifically, cognitive reappraisal negatively correlated with IUI ($r = -0.27, p < .001$) whereas expressive suppression positively correlated with IUP ($r = 0.23, p < .001$). No significant correlation was found between emotion regulation skills and task-specific IU regardless of Balloon Colours and Conditions ($ps > 0.05$).

Table 2
Regression analyses: controlling for covariates.

Predictors	Grey Balloon in Low Uncertainty Condition					Percentage of Bursts				
	Adjusted Average Pumps					Percentage of Bursts				
	B	SE (B)	β	p	95% CI	B	SE (B)	β	p	95% CI
Covariates										
IUP	0.34	1.26	0.26	< 0.01	[0.090, 0.591]	0.004	0.004	0.11	0.26	[-0.003, 0.011]
R ²	0.32					0.29				
F	4.23			< 0.001		3.56			< 0.001	

Covariates include age, gender, educational attainment, personal monthly income, depression, anxiety, and stress score, verbal fluency animal, digit span backwards, and Stroop interference score. Gender, educational attainment, and personal monthly income were dummy-coded. The results of individual covariates were not presented in detail for readability.

3.3. Age effects on IU

3.3.1. IUS-12

The result of the one-way ANOVA showed that there was age main effect for the levels of IUP, $F(2, 297) = 4.39, p < .05, \eta_p^2 = 0.029$. Post hoc test of Bonferroni discovered that young adults ($M = 20.49, SD = 4.15$) reported higher levels of IUP than those reported by older adults ($M = 18.74, SD = 4.29$), which was statistically significant ($p < .05$). Apart from that, no other significant pair was found. For age group difference in IUS-12 total score, $F(2, 297) = 1.12$, and IUI, $F(2, 297) = 1.40$, the results were non-significant ($ps > 0.05$).

3.3.2. BART

Before the main analysis, differences in cognitive abilities (i.e., verbal fluency animal, digit span backwards, and Stroop interference score), emotional state (i.e., score in DASS) and demographic variables (i.e., educational attainment, and personal monthly income) between the two conditions were examined using *t*-test and Chi-square test. The results indicated that there was no significant difference between the two conditions ($ps > 0.05$).

Two sets of mixed ANOVAs (see Fig. 1) were performed to examine the effects of the Condition, Balloon Colour indicating risk level, and Age Group (2x3x3 mixed design) on (a) the adjusted average pumps and (b) the percentage of bursts. Because the assumption test of sphericity was violated in the analyses, the Greenhouse-Geisser was adopted to correct degrees of freedom. Bonferroni post hoc tests were used to investigate the significant effects when applicable.

3.3.2.1. Adjusted average pumps. The main effects of Condition, $F(1, 284) = 75.70, p < .001, \eta_p^2 = 0.21$, Balloon Colour, $F(1.28, 363.87) = 624.75, p < .001, \eta_p^2 = 0.69$, and Age Group, $F(2, 284) = 14.65, p < .001, \eta_p^2 = 0.09$, were all significant on the adjusted average pumps. Participants in the high uncertainty condition ($M = 6.20$) had a lower adjusted average pumps than in the low uncertainty condition ($M = 8.64$). In terms of Balloon Colour, the higher the initial risk of explosion, the lower the adjusted average pumps of that colour balloon (Blue balloon: $M = 4.06 < Purple\ balloon: M = 6.75 < Grey\ balloon: M = 11.46, ps < 0.05$). The main effect of Age Group revealed that older adults ($M = 6.45$) had significantly lower adjusted average pumps than middle-aged adults ($M = 7.54, p < .05$) and young adults ($M = 8.28, p < .001$). No other significant comparison was found.

The main effect of age also depends on the Balloon Colour, as shown in another significant two-way interaction between Balloon Colour and Age Group, $F(2.56, 363.87) = 16.99, p < .001, \eta_p^2 = 0.11$. The follow-up simple main effect analyses revealed that significant age effects were found in Purple and Grey Balloon ($ps < 0.05$), but absent in the Blue Balloon ($ps > 0.05$). Specifically, in both Purple and Grey Balloon, older adults had lower adjusted average pumps than the middle-aged and young adults, which follows a similar pattern described in the main effect of age. Additionally, in Grey Balloon, middle-aged adults also had a lower adjusted average pumps than young adults.

There is a three-way interaction between Condition, Balloon Colour,

Table 3
Correlation.

Variable	<i>n</i>	<i>M</i>	<i>SD</i>	Age	IUS-12	IUP	IUI	ERQR	ERQS	Verbal Fluency Animal	Digit Span Backwards	Stroop Interference Score	DASS Depression	DASS Anxiety	DASS Stress	
Age (range = 20–79)	300	48.72	17.51	–												
IUS-12	300	30.32	7.03	–0.11	–											
IUP	300	19.70	4.29	–0.21**	0.87**	–										
IUI	300	10.62	3.92	0.03	0.84**	0.47**	–									
ERQ																
ERQR	300	29.84	6.57	–0.04	–0.13*	0.03	–0.27**	–								
ERQS	300	15.72	5.18	–0.17**	0.20**	0.23**	0.11	0.16**	–							
Cognitive Abilities																
Verbal Fluency Animal	300	21.31	5.36	–0.26**	0.01	0.06	–0.04	0.05	–0.30	–						
Digit Span Backwards	300	5.93	1.75	–0.25**	0.01	0.06	–0.04	0.13*	0.03	0.21**	–					
Stroop Interference Score	300	11.37	8.34	0.35**	–0.04	–0.10	0.04	–0.09	–0.08	–0.24**	–0.20**	–				
DASS																
Depression	300	2.60	3.09	–0.18**	0.42**	0.37**	0.36**	–0.25**	0.19**	0.05	0.04	–0.01	–			
Anxiety	300	2.46	2.49	–0.13*	0.42**	0.39**	0.32**	–0.11	0.29**	–0.05	–0.01	0.04	0.53**	–		
Stress	300	4.59	3.84	–0.12*	0.53**	0.50**	0.41**	–0.22**	0.23**	0.03	0.03	0.05	0.69**	0.71**	–	
BART																
High Uncertainty Condition																
Blue Bursts	150	0.5323	0.1991	–0.01	–0.05	–0.01	–0.07	0.05	–0.15	0.08	0.03	–0.01	–0.01	–0.10	–0.10	
Purple Bursts	147	0.3500	0.1584	–0.25**	0.05	0.07	0.02	0.01	–0.07	0.06	0.09	–0.14	0.12	–0.02	0.05	
Grey Bursts	146	0.2380	0.1358	–0.47**	0.02	0.08	–0.05	–0.06	0.15	0.16	0.19*	–0.20*	0.18*	0.06	0.05	
Blue Pumps	146	4.19	1.40	0.05	–0.09	–0.10	–0.06	0.08	–0.04	–0.09	–0.05	0.09	–0.04	–0.16	–0.12	
Purple Pumps	147	5.95	2.45	–0.18*	0.01	0.04	–0.03	0.01	0.05	0.03	–0.07	–0.12	0.10	0.02	–0.03	
Grey Pumps	149	8.75	4.50	–0.37**	0.06	0.11	–0.01	–0.06	0.04	0.17*	0.09	–0.19*	0.14	0.08	0.05	
Low Uncertainty Condition																
Blue Bursts	148	0.4229	0.1411	–0.02	0.02	0.04	–0.01	0.05	0.01	0.04	0.15	0.17*	0.01	0.07	0.10	
Purple Bursts	150	0.4046	0.1592	–0.29**	0.04	0.15	–0.10	0.07	0.14	0.15	0.03	–0.05	0.03	–0.02	0.08	
Grey Bursts	150	0.4012	0.1648	–0.31**	0.08	0.16*	–0.04	0.04	0.13	0.15	0.08	0.04	0.07	0.06	0.13	
Blue Pumps	150	3.97	1.24	–0.09	0.07	0.15	–0.04	0.04	0.10	0.08	0.04	0.05	–0.05	–0.01	0.06	
Purple Pumps	147	7.66	2.52	–0.28**	0.01	0.11	–0.10	0.02	0.08	0.18*	0.09	0.06	–0.06	–0.10	–0.06	
Grey Pumps	149	14.40	5.75	–0.26**	0.13	0.23**	–0.02	0.03	0.15	0.12	0.02	0.05	0.02	–0.02	0.14	

IUS-12 = Intolerance of Uncertainty Scale, 12 items. IUP = Prospective Intolerance of Uncertainty. IUI = Inhibitory Intolerance of Uncertainty. ERQ = Emotional Regulation Questionnaire. ERQR = Emotional Regulation Questionnaire Reappraisal. ERQS = Emotional Regulation Questionnaire Suppression. DASS = Depression Anxiety Stress Scales. BART = Balloon Analogue Risk Task. Bursts = Percentage of Bursts. Pumps = Adjusted Average Pumps.

The missing values in BART were due to the exclusion of outliers which fell out of 2.5 SD and invalid values after computing the adjusted average pumps. Particularly, three participants burst all the Blue balloons in the high uncertainty condition (zero divided by zero), which led to the exclusion.

* $p < .05$. ** $p < .01$.

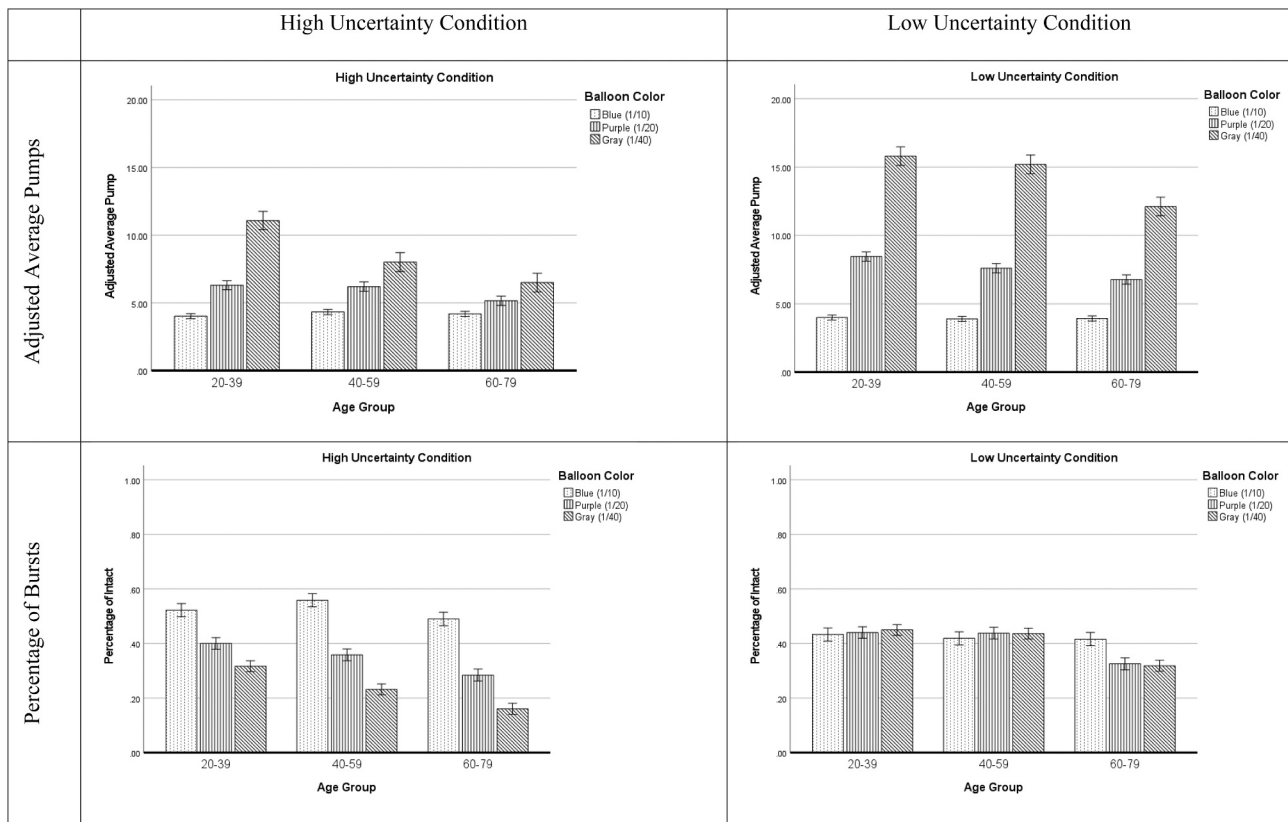


Fig. 1. Adjusted average pumps and percentage of bursts. Error bars represent +/- 1 SE.

and Age Group, $F(2.56, 363.87) = 2.92, p < .05, \eta_p^2 = 0.02$, so that the Balloon Colour x Age Group interaction was modified by Condition. Follow-up simple main effect analyses revealed that there was no significant age difference in the Purple Balloon of high uncertainty condition ($ps > 0.05$), but there was a significant difference in the low uncertainty condition. Specifically, older adults had a lower adjusted average pump than the younger adults in the purple balloon of low uncertainty condition ($p < .01$). In the Grey balloon, although two pairs of comparisons between age groups became non-significant in the two conditions (in the low uncertainty condition, differences became non-significant between middle-aged and young adults; in the high uncertainty condition, the differences became non-significant between older adults and middle-aged adults, $ps > 0.05$), the significant age effects largely follow the same pattern described in the Balloon Colour x Age Group interaction. In general, it is observed that the older the age group, the lower the adjusted average pumps, particularly in Purple Balloon of the low uncertainty condition and Grey Balloon of both conditions.

When the covariates (i.e., demographic factors, emotional state and cognitive abilities) were considered, the results showed a highly similar pattern for main effects and interaction effects, except the three-way interaction (Condition x Balloon Colour x Age Group) was no longer significant, $F(2.63, 308.75) = 2.03, p = .12$. In other words, the interaction between Balloon Colour and Age Group no longer depends on the Condition.

3.3.2.2. Percentage of Bursts. There were significant main effects for Condition, $F(1, 287) = 7.67, p < .01, \eta_p^2 = 0.03$, Balloon Colour indicating risk level, $F(1.91, 548.73) = 131.53, p < .001, \eta_p^2 = 0.31$, and Age Group, $F(2, 287) = 16.38, p < .001, \eta_p^2 = 0.10$. Participants in the high uncertainty condition ($M = 0.37$) had a significantly lower percentage of bursts than in the low uncertainty condition ($M = 0.41$). In terms of Balloon Colour, all pairs of comparisons were significant ($ps < 0.001$) so that the higher the initial risk of explosion, the lower the percentage of

bursts (Blue: $M = 0.47 > Purple: M = 0.38 > Grey: M = 0.32$). For the main effect of Age Group, older adults ($M = 0.33$) had a significantly smaller percentage of bursts than the middle-aged ($M = 0.41, p < .001$) and young adults ($M = 0.43, p < .001$).

A significant two-way interaction was discovered between Balloon Colour and Age Group, $F(3.82, 548.73) = 7.04, p < .001, \eta_p^2 = 0.05$. It was revealed that the main effect of Age Group was found only in the Purple Balloon and Grey Balloon, but not in Blue Balloon. In particular, older adults had a significantly lower percentage of bursts than middle-aged and young adults in both Purple and Grey Balloon ($ps < 0.001$). Additionally, in the Grey Balloon, middle-aged adults also had a significantly lower percentage of bursts than young adults ($p < .05$).

However, as indicated in the marginally significant three-way interaction, Condition x Balloon Colour x Age Group, $F(3.82, 548.72) = 2.41, p = .05, \eta_p^2 = 0.02$, the difference between middle-aged and young adults in Grey Balloon was modified by the Condition, so that it was only observed in the high uncertainty condition ($p < .01$), but not in the low uncertainty condition ($p > .05$). Apart from that, the Balloon Colour x Age Group interaction was highly similar across the two conditions. Therefore, despite the marginally significant three-way interaction, it is implied that older adults, in general, had a lower percentage of bursts than middle-aged and young adults in Purple and Grey Balloon in both of conditions. This is similar to the findings of the age effect reported in the adjusted average pumps.

When accounted for the covariates, the significant main effects and interaction effects remain highly similar. One notable difference emerged when compared to the initial model without covariates. The three-way interaction effect was no longer significant, which implied that the Balloon Colour x Age Group interaction no longer depends on the Condition, $F(3.83, 452.17) = 1.82, p = .13$. Nevertheless, as described in the initial model, only one pair of age group difference in Grey Balloon seemed to be dependent on the Condition.

The parameter estimates were obtained after the chains had

converged (R-hat = [0.99,1.01]). The posterior distributions of each parameter for each condition per group were shown in Fig. 2.

3.3.2.3. Exploratory modelling analysis. Group differences were observed in three parameters: risk preference, inverse temperature, and loss aversion. Specifically, the young group showed credibly lower risk preference than the middle-aged group $\{\Delta\rho = -0.013, 95\% \text{ highest density interval (HDI): } [-0.026, -0.001], \text{ Fig. 2C}\}$; they also exhibited lower inverse temperature than both middle-age group $\{\Delta\tau = -0.759, 95\% \text{ HDI: } [-1.272, -0.246], \text{ Fig. 2D}\}$ and the older group $\{\Delta\tau = -1.403, 95\% \text{ HDI: } [-1.983, -0.823], \text{ Fig. 2D}\}$. Furthermore, loss aversion increased from the younger group to the middle-aged group $\{\Delta\lambda = -0.405, 95\% \text{ HDI: } [-0.640, -0.170], \text{ Fig. 2E}\}$, and from the middle-aged group to the older group: $\Delta\lambda = -0.895, 95\% \text{ HDI: } [-1.304, -0.485], \text{ Fig. 2E}\}$.

On the other hand, condition effects were also observed. Under ambiguous condition, individual showed a higher prior belief of burst $\{\Delta\phi = 0.021, 95\% \text{ HDI: } [0.011, 0.032]\}$, lower risk preference $\{\Delta\rho = 0.012, 95\% \text{ HDI: } [0.003, 0.020]\}$, higher inverse temperature $\{\Delta\tau = 1.489, 95\% \text{ HDI: } [0.987, 1.992]\}$, and higher loss aversion $\{\Delta\lambda = 0.502, 95\% \text{ HDI: } [0.214, 0.790]\}$. Further analysis indicated that these condition effects were found only in the middle-aged and older groups, but not in the younger group (Fig. 2B-E): relative to unambiguous condition, the middle-aged group in ambiguous condition showed increased prior belief of burst $\{\Delta\phi = 0.030, 95\% \text{ HDI: } [0.012, 0.049]\}$, reduced risk preference $\{\Delta\rho = -0.010, 95\% \text{ HDI: } [-0.017, -0.003]\}$, higher inverse temperature $\{\Delta\tau = 2.195, 95\% \text{ HDI: } [1.252, 3.120]\}$, and higher loss aversion $\{\Delta\lambda = 0.743, 95\% \text{ HDI: } [0.386, 1.114]\}$. Similarly, the older group under ambiguous condition exhibited higher prior belief of burst $\{\Delta\phi = 0.018, 95\% \text{ HDI: } [0.002, 0.034]\}$, higher inverse temperature $\{\Delta\tau = 1.878, 95\% \text{ HDI: } [0.851, 3.010]\}$, and increased loss aversion $\{\Delta\lambda = 0.791, 95\% \text{ HDI: } [0.064, 1.518]\}$ compared to unambiguous condition.

4. Discussion

Partially supporting the first hypothesis, younger adults self-reported higher IUP than older adults, but no significant differences were found in the self-reported IU scores between the middle-aged vs. young/older adults, and no difference on IUI or the IUS-12 total score was found. This

is in line with the meta-analytic results that overall IU reduces with age [12]. The differential effect on IUP vs. IUI was similar to that reported in [33], that IUP is more influential on the emotional state of Chinese adults than IUI. However, as anticipated, a different picture about age effect was observed from the behavioural choices on the BART. Older adults overall had less pumps than the middle-aged and young adults. Additionally, with the Grey balloons, middle-aged adults also had less pumps than young adults. The same pattern was found for the indicator of bursts, where the older adults had less bursts than the middle-aged or younger adults, and the middle-aged adults had less bursts than young adults. From the exploratory modelling analysis, it was found that young adults showed lower risk preference, whereas older adults showed higher loss aversion. These indicate age differences in perceived reward for each pump in relation to loss aversion: young adults tolerated more potential losses whilst older adults had higher loss aversion. In addition, young adults also showed lower inverse temperature, indicating more random choices. Condition effects were found in middle aged and older adults, but not among the younger adults. In other words, the young adults appeared to have more willingness in trying different solutions when confronted with a new task involving uncertainty, and at the same time, less sensitive to risk changes in the environment. Older adults appeared to experiment with new solutions less when completing a new task involving uncertainty, and were more sensitive to risk changes in the environment. The age differences are most in line with the Socio-emotional Selectivity Theory [17]. Our ability to emotionally accept uncertainty may increase with age, and we may aim towards protecting our wellness instead of maximizing resources (i.e., more conservative behaviourally).

Therefore, there was a seemingly discrepancy on the IUS-12 vs. BART: whilst self-reported IU decreases with age, behavioural IU increases with age overall. We interpreted this in terms of the different aspect of uncertainty that the two measures captured; IUS-12 may reflect one's belief about their general ability to manage uncertainty in their daily lives, whilst the BART reflects the momentary decisions under risk in an unfamiliar context. This is in line with previous studies that found older adults to be better at reducing states of negativity [22,23], though self-perception may not always translate to actual behaviour [24]. Therefore, our results highlighted the complexity of tolerance of uncertainty and showed the importance of integrating both explicit and implicit or self-perception and behavioural measures for studies on this

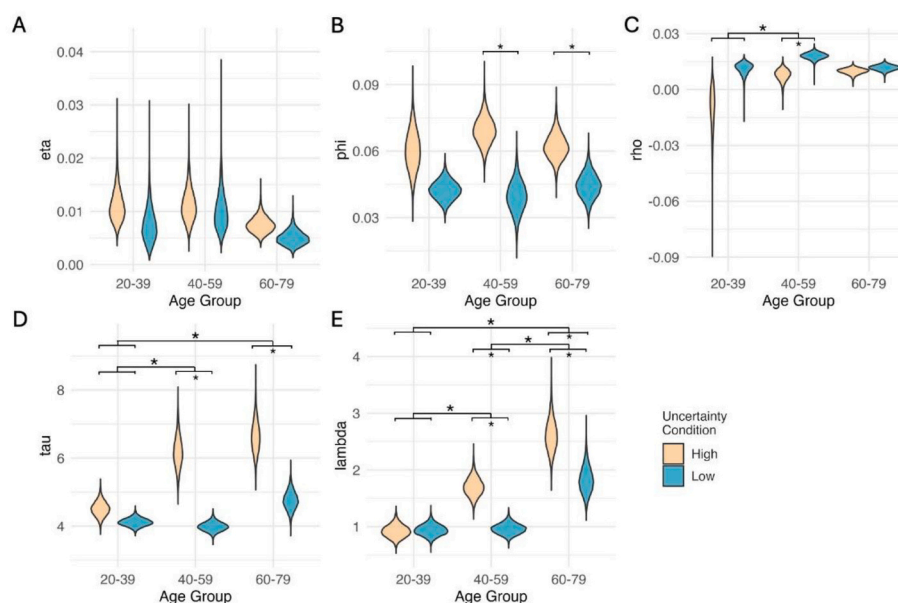


Fig. 2. Posterior distributions of group-level parameters estimated using the EWMV model. (A) Updating exponent. (B) Prior belief of burst. (C) Risk preference. (D) Inverse temperature. (E) Loss aversion. Asterisks indicate that the 95% HDIs for the differences in group means do not include zero.

topic. A recently published paper using the German version of the IUS-18 and an affective decision task also reported a lack of association between self-report IU scores and behavioural choices on the task [51]. One possible explanation is that the context affects the degree in which one's general IU relates to their momentary behaviours [25]; when there was higher perceived threat (and motivation), such as a potential loss of a bonus point for undergraduate students, their level of IU especially IUP was more associated with behavioural conservatism, whilst such loss was less threatening/motivating to community participants [25]. On the other hand, self-report measures such as the IUS-12 are considered trans-situational [4], and so may reflect the person's self-perception of their general tendency in the past rather than for specific and/or new situations. Further studies are needed to better understand the situations in which self-perception and behavioural responses converge or diverge, as some previous studies did find positive associations between IU, anxiety symptoms and behavioural conservatism [27,52]. Future studies may specifically test for the potential influence of cultural effects as part of the contextual factors, such as collectivism and the degree of influence from social networks [33].

In terms of the associations between IU and emotion regulation, expressive suppression was found to be related to higher IUP, whereas cognitive reappraisal was associated with lower IUI. Overall, these are in line with previous studies. For example, Sahib et al. [53] found that IU predicted the use of inhibition-based emotion regulation strategies such as suppression and avoidance. As proposed in Marchetti et al. [5], it is possible that high IU motivates people to respond to uncertainty in a rigid manner, and such inflexibility (e.g., emotional suppression) puts one at higher risk of emotional disorders. When looking at age differences, there was a negative correlation between age and level of expressive suppression, but no age difference in cognitive reappraisal was found. Therefore, similar to the speculation in Yu et al. [12], there was evidence partially supporting a reduction in inhibition-based emotion regulation with healthy aging, although more research is needed to explore what adaptive methods are used by older adults instead in uncertain situations. This could be achieved by using more comprehensive measures of emotion regulation in future studies, exploring additional mechanisms such as acceptance/mindfulness, and physiological relaxation [54].

Based on the results, professionals working with adults of various ages may consider tailoring their assessment and intervention based on the likely emotional and behavioural tendencies of the corresponding developmental stage. When working with young adults, it will be helpful to assess the presence and degree of inhibition-based emotion regulation, such as expressive suppression, and self-perception of one's ability and confidence about managing uncertainties. If avoidance has been identified, strategies such as exposure to the affective, cognitive, and physiological reactions towards uncertainty can be incorporated into the intervention [54]. On the other hand, when working with older adults, assessment of possible over-confidence in managing potential risks in new challenges/situations would be helpful. In terms of emotion regulation, building on older adults' preference for emotional wellness, positivity [17] and lowered expressive suppression, strategies such as mindfulness and acceptance can be considered [54].

Limitations of the current project are acknowledged. Considering the need to keep to a reasonable testing duration for data collection, especially with recruiting middle-aged adults who often had busy schedules, we selected the most relevant measurements only. Further studies are recommended to include other methods to capture IU more comprehensively, such as using other computerised tasks, or ecologically valid methods such as ecological momentary assessments, to check if the current results are generalisable or if they might be specific to the BART used. Other anxious traits, such as anxiety sensitivity and neuroticism, should also be measured to better understand the shared or unique nature of IU [55]. Further research may also be needed on establishing whether and how different components of IU may play distinct roles in influencing behaviour. Possible explanations in relation to cultural and

contextual factors need to be tested empirically. The current sample was recruited from the community. Further studies on clinical samples would be useful in understanding the interplay between intolerance of uncertainty, aging and mental health symptoms across adulthood. Future studies should test the generalisability of the current results in more diverse samples, as the current sample only consisted of ethnically Chinese participants, and gender was defined as a binary variable.

5. Conclusion

In conclusion, we examined IU using both a behavioural task (BART) and a self-report measure (IUS-12) in a sample of young, middle-aged and older adults in Hong Kong, China. Whilst self-reported IUP decreased with age, more certainty-seeking behaviours on the BART were observed instead on the BART. Results inform possible developmental changes in the perception and ability to manage uncertainty across adulthood. Suggestions were given for more tailored interventions for both younger and older adults.

CRedit authorship contribution statement

Yuan Cao: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Conceptualization. **Gerald S.Y. Kwan:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Yuanwei Yao:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Jiajing Chen:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Mandy H.M. Yu:** Writing – review & editing, Methodology, Investigation, Data curation. **David H.K. Shum:** Writing – review & editing, Supervision, Project administration, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Yuan Cao reports financial support was provided by The University of Hong Kong. Yuan Cao reports financial support was provided by The Hong Kong Polytechnic University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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