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Scientific background

This document holds a summary of the scientific background supporting this firefighter hydration project.

Why does the body need water?
Water is the human body's main component (at least 60%) and is vital for organ function and thermoregulation. The regulation of fluid balance is closely linked to the regulation of electrolyte balance. In the kidneys, the excretion of water and electrolytes is regulated by hormones, particularly the antidiuretic hormone, and aldosterone.[1] When there is excess water in the body, diluted urine is excreted.[2] If the concentration of electrolytes in body fluids becomes too high, the thirst center in the brain is stimulated and this leads to a feeling of thirst and reduced excretion of water by the kidneys.[1] Water loss occurs through urination, defecation, respiration, and sweating. Losses by sweating are generally small, but they can increase to several liters per day in warm environments, especially when combined with manual labor or exercise.[3]

How much water does a wildland firefighter (WLF) need?
Daily water requirement varies from person to person.[4] Despite the advanced technological capabilities that science employs today, a universal daily adequate water intake has not been defined precisely for any demographic group [4], let alone for WLFs. A limited number of water turnover studies have been performed based on real fire suppression activities over time using water enriched with deuterium. The studies conducted between 1997 and 2015 show a mean water turnover of 7.0$\pm$1.7 L/d [5], 6.7$\pm$1.4 L/d [6], and 6.6$\pm$2.1 L/d [7], 9.5$\pm$1.7L/d [8], across a total of 74 participants.

What is the difference between clinical dehydration or not drinking a suboptimal amount of fluid, and why is this important for this research proposal?
There are multiple ways to determine hydration status. To detect severe dehydration, blood plasma osmolality may provide the most valid and precise measurement of body hydration status [9], as the body regulates blood plasma levels within a tight range (285-296 mOsm/kg).[10] This method is especially useful to detect acute overhydration or severe clinical dehydration.[11] As a result, plasma osmolality is in most cases not a useful indicator of fluid intake, while urinary markers are much more prone to detect a low fluid intake, as a low 24-hour fluid intake has been inversely associated with a high urine concentration.[12] The National Athletic Trainers' Association position statement [13] provides multiple definitions for hydration, and from a practical perspective euhydration, dehydration, and hypohydration are the most important for this proposal. Euhydration suggests that the body is in an optimal fluid state, whereas dehydration is the active process of losing body water, for example, during activity, and finally, hypohydration indicates a state in which the fluid that is lost is not effectively replaced [13], at the same time a high urine concentration can occur without having a body water deficit, which is determined as "underhydration", when consuming to low amount of fluids.[2]

How to detect a low fluid intake using urine concentration?

Elevated urine concentration can be caused by inadequate fluid intake, and therefore the measurement of urine osmolality or urine specific gravity[13] can be a useful marker.[2,14] Different cut-off values for urine concentration markers, such as osmolality and urine specific gravity (USG), have been proposed, indicating cut-offs to determine hydration.[10,15] Although the type of sample collected (24-hour vs. morning or afternoon spot urine sample)[16–19] may influence concentration, most studies have been using cut-off values in a range of 700-800 mOsm/kg[14,20–23] or the USG equivalent[10,14,22,24] to indicate poor hydration status. While osmolality allows for determining concentration more precisely (as it can be measured on a wider scale), USG correlates very well with urine osmolality (U_{osm}) with an r≥ 0.995.[10,25]

Do WLFs consume enough fluid?

Individualized recommendations for fluid needs must be based upon many factors, including anthropometrics, type of exercise performed, duration and intensity of the exercise, total body weight change (including sweat rate and urine losses), environmental factors (including fire heat exposure), heat acclimation status, rehydration opportunities, type of fluid consumed, and pre-exercise hydration status.[26] General recommendations are available for fluid intake on the job. These recommendations normally range between volumes of 500-1000 mL per hour (16 to 32 fl. oz.).[27] Scientific evaluations have reported lower intakes than recommended starting at 250-300 mL[28,29], up to 500-640 mL[30,31], and high intakes up to 2141±838 mL over a two-hour period (~1070 mL per hour) have been reported in hot conditions.[29]
In the end, hydration status is based not only on what is consumed during a work shift, but also during the rest of the 24-hour cycle. In WLF research, urine concentration is often reported as USG, providing good insight into the general hydration status of WLFs. In most studies reporting USG, a substantial part (40-60%) of WLFs at baseline have USG above a cut-off value ≥1.020. This can also be confirmed by a report by Rhan et al. (2016), our Wildfire Conservancy project partner, reporting that at least half of the n=95 CAL FIRE WLFs they measured had a USG value ≥1.020.[32] This suggests that roughly half of WLFs could optimize their daily fluid intake.

Why do WLFs report urine with a high concentration?

The short answer is that WLFs drink less than they need, resulting in a high urine concentration.[2] The extended answer is that body fluid balance is complex and dynamic, including a matrix of intracellular fluid, interstitial fluid, and blood plasma that allows for fluid exchange between compartments.[33] The body can gain water (fluid and food intake) and lose water (urine, sweat, feces, and respiratory vapor).[33] Physiological factors influencing body fluid balance are fluid intake vs. sweat rate and urine loss, and sodium intake vs. sweat sodium loss, all influenced by:

1) Workload (which is a combination of work (activity) duration, intensity, and the balance between activity and rest) will result in the metabolic generation of heat in WLFs.[34] During a 12-14 hour work day WLFs hike over rough terrain, construct fire lines, lay hose, operate chainsaws, and clear brush during wildfire management and training activities, often performed in hot environments, and with a high caloric

expenditure ranging from 3000-6260 kcal per day.[34] WLFs can self-regulate their fluid consumption behavior and work rate to leave the fireground euhydrated [35], but increasing the number of rest breaks and fluid intake (including sufficient electrolytes) have been suggested as important modifiable variables.[34,36]

2) Fitness level suggested to match a maximal oxygen uptake ($VO2_{max}$) of 45 ml/kg [37] are often tested using a pack hike test [38], but WLFs may not always meet that requirement. A substantially lower aerobic capacity has been measured in both certified and uncertified WLFs.[39] Having a good basic fitness level is important, as we have seen that fitness level is substantially influenced by environmental heat stress, resulting in significantly higher core temperatures in slower and lesser-fit mountain hikers when compared to moderated conditions.[40]

3) Work settings in hot environments often bring inherent hazards, so there are occupational standards (such as work-to-rest ratios and thermal exposure limits) designed to reduce strain and the likelihood of thermal injury and impacts from heat strain.[41] Heat gain during firefighting is the product of energy expenditure (metabolic heat) and radiative heat exposure from fire (and solar radiation), and it can override the efficient sweat rate capacity of the body, particularly in dry environments, such as in the U.S. southwest. As a result, WLF bodies can easily heat up while suppressing fires, with raised core and skin temperatures, increased cardiovascular strain, and negatively influenced cerebral function.[42] These uncomfortable conditions lead to increased breathing rate, altered muscle metabolism, and inadequate oxygen delivery to working muscles, factors that facilitate fatigue and prevent (tactical) athletes from maintaining elevated work rates during prolonged activities.[43] Normally, under hot conditions causing heat stress, work capacity is lowered to avoid hyperthermia [44], and if work rate is not altered, heat related illness can occur.[45,46] Although heat illness related symptoms, such as dizziness, headache, nausea, and muscle cramps, have been reported in 39–57% of structural firefighters [47,48], they have not been well documented in WLFs.[46] A total of 30-50% of all firefighters report symptoms related to heat stress [47,48], resulting in actual thermal stress injuries that result in temporary medical leave of absence being around 3-4%.[49] Self-reported symptoms, scored over a period of 12-months by a sample including WLFs, related to heat stress (can be tied to hydration status) include: dizziness (56.6%), headache (48.8%), nausea (47.5%), muscle cramps (45.7%), and confusion (33.2%).[47] It is worth noting that in a sample of n=674 wildland and structural firefighters, at least 25% reported experiencing these symptoms more than 10 times a year.[48] One out of two female structural firefighters from the U.S. reported having a heat related illness.[47]

When fluid intake over a 24-hour period does not match fluid loss (driven by the elements mentioned above), the body will retain the available fluid, resulting in higher urine concentration also known as underhydration.[2] Depending on the frequency with which a WLF does not meet their fluid needs, they can also develop intermittent dehydration (in which WLFs likely do not drink enough during their shift to compensate for fluid loss and recover well-hydrated baseline after their work shift), or it may lead to chronic hypohydration in which fluid loss is not effectively compensated at any time during the day.[50]

<u>What happens when WLFs are chronically hypohydrated?</u>
Fluid balance is regulated through the effects of antidiuretic hormones.[51] Loss of body water resulting in dehydration raises plasma osmolality levels, which in turn stimulates the release of vasopressin, reducing the amount of water lost through the kidneys.[52] Despite this feedback loop, sweating induced by exercise may easily override the body's fluid-saving mechanisms. If fluids are not properly replaced, impaired exercise capacity may limit performance and exertion may ensue.[53–55] Conversely, the atrial natriuretic peptide is secreted in response to increased atrial blood volume, and it promotes sodium, hence water excretion.[56]

Dehydration has many negative side effects, such as the exacerbation of fatigue development, cramping, heat exhaustion, and heat stroke, as well as decreased cognitive function, and, in extreme cases, loss of consciousness and death.[13,52,55,57–59] Even levels of hypohydration as low as 1% of total body weight loss [55] may cause a myriad of problems in athletes across all exercise types.[52,57–59] The hindrance of performance when (tactical) athletes are improperly hydrated or insufficiently replace fluid losses is widely accepted, especially when the net body weight loss due to exercise-related sweating exceeds more than 2% of body mass.[25,55] Overall, dehydration or hypohydration will impair exercise performance and capacity [54], as well as the state of mood that greatly impacts the process and quality of everyday decision-making.[60] As such, negative mood states may lead to poor judgment and irrational decisions, increasing risky behaviors and susceptibility to adverse events.[60] Sustained heat exposure and dehydration were positively associated with negative mood disturbances and poor decision-making in military personnel.[61] Given the similarities in occupations (i.e., physical performance demands and often extreme external environments), firefighters, too, are likely at greater risk. Effective decision-making is essential in a high-stress environment [62], such as during a fire emergency, to ensure the success and safety of the firefighting operation. Yet, poorly hydrated firefighters exhibiting negative mood states may make poor safety-related decisions, such as improper fastening of equipment, not securing a fire scene, or disrupted communication with firefighter team members.[63] These failures could increase the time needed to effectively control fire scenes, decrease team cohesion and overall productivity, and increase firefighter and civilian injury and death rates.[63] In addition, optimal hydration may have positive effects on general health, as optimal water intake may slow down the aging process [64], which is important as the biological age of firefighters may often exceed their actual age.[65] WLFs are advised to consume enough fluid to stay well-hydrated to maintain optimal performance, mood, and cognitive states.[63,66]

<u>Can education improve hydration?</u>
There is limited and inconsistent evidence that hydration education can improve [67,68] or not improve [53,69] hydration markers at the short term in children and adolescent athletes. Despite that the available evidence for effective education is limited [13], education should address a) the consequences of dehydration or fluid overload, b) hydration-monitoring

strategies, c) how to use reliable and valid measures of pre- and post-activity body mass measurements to assess fluid status, d) how to schedule activities and modify work-break ratio to optimize hydration and improve safety, and e) environmental influences on fluid requirements.[13]

What hydration self-assessment education is currently available?

Some WLFs receive training in health and performance issues. Currently, in Arizona, this type of training is aimed at module leaders who are expected to pass this knowledge on to their crews, but the relevant course is organized on a voluntary basis. The Forest Training Officer, Jonathan McLaughlin, informed us that the training is not done in a formal course and can occasionally be overlooked. Additionally, handbooks from fire service organizations are available. For example, the U.S. Department of Agriculture Forest Service Health and Safety Code Handbook briefly provides fluid recommendations and the need for fluid intake monitoring.[56] The Incident Response Pocket Guide [70], something that WLFs are required to carry on their person at all times, mentions that WLFs need to bring fluid (additional resources) but it offers no further recommendations. This is in contrast with the Australian NSW Rural Fire Service Firefighters' Pocket book, as it includes a Uc chart with some simple recommendations about fluid intake aligned with Uc.[57] Although it is not uncommon to have a Uc chart at the station and/or in its restroom, it appears (based on published research [71], and onsite conversations) that clear instructions or training about how to monitor hydration status are not presented in a standardized way or are not available at all.

Is the current implementation of hydration self-assessment strategies effective?

The fire service is aware of the risks that come with the job. Therefore, there is a tendency to implement risk management strategies, for example, to reduce injuries.[71] Awareness, knowledge, and the use of control strategies were evaluated in what appears to be the most detailed study on the topic. It included 450 structural firefighters that completed three cross-sectional surveys during a 2-year period.[71] During this study, a Uc chart was used that had a header stating, "Are You Hydrated? Urine Hydration Chart." It used fixed scales for being hydrated (the target, reflected in a green box), being dehydrated (in a yellow box), or being severely dehydrated (in a red box) that were lined up with eight urine colors, from very light yellow to brown. Over time, slightly less than half of the firefighters said their hydration status had improved [71], but no independent hydration markers were collected to confirm this. Although no standardized instructions were given on how to assess their Uc, which is important to optimize the assessment accuracy [72,73], the paper shows the potential of using simple charts for self-assessment in the fire service.

The current situation is that WLFs are informed about the importance of self-assessment but lack well documented written instruction on how to perform these assessments. Hydration self-assessment is supported by fire service leadership.[74,75] In the U.S., researchers employed by the Forest Service have published applied articles on hydration advice [27,76], and their web pages refer to WLFs fluid needs [77], but despite the emphasis that education is important, specific strategies for implementation of this education, coaching, and counseling to optimize measurements are not described in detail in the consensus literature.[9,13] It is known that behavior change moves through different stages.[78] Simplified, behavior change moves from considering if the assessment of hydration status is needed, to the willingness to self-assess hydration status, to adopting a way to assess hydration status. To ensure effective behavior change, an individual needs to feel that self-assessment is under their control.[79,80] Self-management can be an effective integral strategy to manage long term health conditions.[81,82] At the same time, best practice strategies are not always available [81], and although there is evidence that specific hydration markers could lead to an accurate self-assessment of hydration status, this evidence has been based largely on investigator scores and not on actual self-assessment.[83,84] The publications that report self-assessment show that subjects are less accurate than trained investigators.[85,86] This indicates the importance of education and training, as well as standardization of the assessment.[72] Aside from these elements, the actual training on an individual level should include goal setting (defining the individual's objectives), successful monitoring (including how to perform the self-assessment), short- and long-term motivation strategies, problem-solving (developing adaptive strategies), and contingency management (reinforcement of this new behavior).[87] This training frame should be integrated into future WLF hydration self-assessment implementation strategies.

<u>Selecting hydration self-assessment methods to determine a high urine concentration</u>
There is widespread consensus regarding treatment, but not the diagnosis of impaired hydration status.[88] As we have explained, different phases of dehydration, hypohydration and underhydration can be determined using clinical biomarkers in the blood (i.e., plasma osmolality) and in urine (i.e., osmolality and specific gravity), but these measurements cannot be used for self-evaluation.[88] The requirements for self-assessments are that measurements are simple to perform, demand little time, are easy to interpret, and preferably having high validity, resulting in an accurate selection of well hydrated vs. not well hydrated (based on as accurate as possible classification of the urine sample with a low vs. high urine concentration). Armstrong et al. (2016), including Kavouras, one of our research team members, explained that diagnosis of dehydration in clinical practice needs to be optimized. Therefore, they rated the scientific and clinical value of hydration assessment techniques; rated the time, monetary cost, and technical expertise required; and incorporated the conclusions of previously published review articles. Based on this, they concluded (see Appendix 4) that the following items would be suitable for patient self-evaluation: 1) thirst sensation, 2) blood-pressure change, 3) heart rate change, 4) urine color, and 5) body mass. Other markers, such as bioelectrical impedance analysis and saliva osmolality testing, were not deemed suitable for self-assessment.[88]

The available validation studies in the hydration self-assessment literature focus on determining the accuracy of measurements toward: 1) Assessing acute dehydration (i.e., sweat loss during exercise), which includes bodyweight change pre-post exercise [9,13], and markers of cardiovascular function, such as blood pressure and heart rate.[89] Although the use of cardiovascular markers has been integrated in technology, such as smartwatches, the actual accuracy to detect mild hydration is limited and not superior to the markers listed next. [89] And 2) determining chronic underhydration, in which normally no substantial fluid volume is lost but in which the body is working hard to keep the available body fluid in the system, resulting in the production of concentrated urine.[2] Measurements include bodyweight change from baseline, thirst, Uc [90], and other markers directly related to fluid intakes, such as urine volume [12], urine void frequency [83], and urine void duration.[85] There are examples in the literature of combined methods, such as the WUT model, in which "W" stands for bodyweight, "U" for Uc, and "T" for thirst sensation, but validation of this model has been limited to only one study.[91] It has been suggested that single markers do not provide enough evidence to assess dehydration [90]; however, results from the combination of any two of these markers can mean dehydration is likely, and a combination of all three means an assessment of dehydration can be very likely.[84,17] Pilot data from our lab confirms this suggestion.[92] Therefore, firefighters could potentially benefit from a combination of methods that are currently used as single markers. Uc offers the highest self-reported accuracy for classifying samples as being high or low in urine concentration.[93] Its use in combination with other methods should allow for the most efficient detection of a suboptimal hydration status.[13] Investigators showed a 97% diagnostic ability when combining Uc assessment and urine void frequency during a 24-hour period [83], which is promising but confirmation is needed that WLFs can meet this accuracy level when they self-assess their hydration status. As untrained individuals report less accurately than trained investigators [35], multiple markers directly associated with urine concentration should be examined in combination to determine the best methods to use for self-assessment of hydration status.

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